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METHODS AND SYSTEMS FOR MEDICAL LIGHTING

Cross-Reference to Related Application(s)

This application claims the benefit, under 35 U.S.C. §119(e), of U.S. Provisional Application Serial No. 60/454,039, filed March 12, 2003, entitled "Methods and Apparatus for Providing LED Illumination in Medical Interventions," which application is hereby incorporated herein by reference.

BACKGROUND

The diagnosis and treatment of diseases, injuries and other medical conditions requires a wide variety of precision tools, instruments, and systems. The use of those items occurs in a variety of health care environments, including doctor's offices, hospitals, clinics, operating rooms, emergency rooms, pre-operating rooms, and many others. One obstacle to high-quality medical care is the inability of doctors and other health care professionals to see the area on which they are working, such as body cavities during surgery. In addition to difficulties associated with blood, tissues, shadows, and other factors that obscure work areas, shadows, glare, and other optical effects can impair vision and thus affect the quality of work. A need exists for lighting systems that provide improved visibility of medical work areas.

Surgical procedures require sufficient illumination of the surgical field to insure successful interventions. Although current lighting techniques and devices are often adequate, there are a growing list of procedures and surgeries than can greatly benefit from improved lighting. In particular, as medical intervention methods trend toward less-invasive surgical methods, a trend towards smaller surgical wounds and exposures often results in difficulty providing light where it is needed using current lighting devices and fixtures. It is the purpose of this invention to provide for new devices and improved means of illumination for use in a wide variety of medical interventions and procedures.

Although this disclosure focuses on medical applications (for people or animals) this invention can be used anywhere close, detailed inspection is required such as engine inspection, industrial equipment, transportation, and more. This disclosure is not limiting in any way to the application of small light source usage.

In the operating room (OR), lighting is typically provided through movable, overhead-mounted fixtures, which provide light flux. The premise is to aim and direct a lot of this light to insure all areas are adequately illuminated. However, there exists an inherent difficulty with this technique for lighting, particularly in applications where the exposure has the surgeons operating deep in a hole. Ideally, the lighting source would be pointing down into the hole. Unfortunately, this is also the view the surgeon desires so there is a conflict as the surgeon's head and body is often directly occluding the light source. Lighting fixtures must be often adjusted or the surgical personnel must adjust their position so they have good sightlines to the task. These overhead lights are also very bright and, as a result, raise overall illumination levels to insure that task area is well lit. This has the effect of making everything very bright, but the area of interest can often be of high contrast to the surrounding areas and remain relatively poorly lit.

Another means of providing light is the use of fiber optic head-mounted light sources (similar to what a spelunker might wear and used when direct eye-vantage-point illumination is required). The units currently used in ORs are cabled, heavy and, due to the common operating positions for doctors working over the patient, a significant head and neck strain. Illumination is often only well provided by the person wearing the headlamp. If two surgeons are wearing the devices, this bulky hardware results in head bumping and can be 'like two unicorns crowding into the same area' as reported by one surgeon. Further, the tethering of the device to the light source makes switching sides of the table logistically very difficult. In general, doctors and residents do not like to wear headlamps and avoid it whenever possible.

Unfortunately in both of these lighting scenarios, the brightness and the alignment of these lights sources is inadequate. Occlusions by people and equipment

make viewing difficult, especially from more than one vantage point. Eye-aligned sources reduce perspective and eliminate texture cues for depth. The area of interest is often not lit well.

What is of interest are light sources located directly at and illuminating the task area. Other desired properties include glare-free sources capable of being positioned and adjusted freely. This invention provides for light sources directed at surgical areas and provides means of securing these light sources to existing tooling and equipment.

Prostectomies, the removal of the prostrate gland for prostate cancer, are very common with 185,000 cases done per year in the US alone. The exposure for these surgeries deep in the pelvis can be daunting. The surgery is associated with high risk of impotence and urinary incontinence if nerves that course through the surgical field are injured. Blood loss can be significant and could be reduced with better lighting. Surgeons tend to wear headlamps and continue to strive to reduce incision sizes and exposures, but are limited to some extent by lighting issues.

Hysterectomy is the removal of some or all of the uterus, tubes and ovaries through the vagina or abdomen. Hysterectomies are the second most frequently performed surgery in the US with over 600,000 done each year in the US. Roughly 20% of all women have this procedure by the age of 70. Typically the surgery is done through the belly (abdominal hysterectomy) because this provides easier access than through the vagina (laparoscopic assisted vaginal hysterectomies). However, although the approach through the vagina is more difficult, it is thought to be better for the patient because it reduces recovery time. The technique is more difficult for the surgeon and, as a result this is most commonly done through the abdomen. Headlamps must commonly be worn for these procedures. This same argument applies of almost any vaginal medical procedure that would also benefit from better illumination.

Surgery in the spine (cervical, thoracic, and lumbar) presents difficult lighting situations for orthopaedic and neurosurgical spine surgeons. Headlamps are often worn.

In addition to the difficultly of the lighting situation, the procedures can be many hours, thus adding to the difficulty of using headlamps.

Similarly, almost every common dentistry or oral surgery procedure involves working in a dark hole (the mouth) and as such provides difficult lighting situations. These procedures are extremely commonly performed and improved lighting for these tasks would have broad application from the routine cleaning of teeth to complex oral reconstructions.

There are broad classes of procedures that stand to benefit from improved lighting. Among these are ear nose and throat procedures (throat surgeries), thoracic surgeries (thoracotomies for removal of tumors in the lungs), gastrointestinal surgeries (removal of rectal and other cancers), and abdominal trauma surgeries.

SUMMARY

Methods and systems are provided herein for providing improved lighting systems for medical environments, including semiconductor-based lighting systems that are capable of control by a control facility. Such systems offer a wide range of benefits as compared to conventional lighting systems.

Methods and systems are provided herein for providing lighting for a medical environment. The methods and systems include providing a medical tool having a non-lighting function; integrating a light source into the tool; and controlling the light output of the light source to light a work area. The light source may be a semiconductor-based light source. The control facility may include a processor. The tool may be a cutting tool, grasping tool, retracting tool, suction tool, cauterizing tool or other tool.

Methods and systems are also provided for providing a lighting system for a surgical operating environment. The methods and systems include providing a lighting system having a plurality of light sources capable of producing light of variable output characteristics, providing a control facility for the lighting system, and providing a user

interface to the control facility. In embodiments the user interface comprises a voice recognition interface.

As used herein, medical and surgical environments include the various surgical environments described in the background above.

The following patents and patent applications are hereby incorporated herein by reference:

U.S. Patent No. 6,016,038, issued January 18, 2000, entitled "Multicolored LED Lighting Method and Apparatus;"

U.S. Patent No. 6,211,626, issued April 3, 2001 to Lys et al, entitled "Illumination Components,"

U.S. Patent No. 6,548,967, issued April 15, 2003, entitled "Universal Lighting Network Methods and Systems;"

U.S. Patent Application Serial No. 09/805,368, filed March 13, 2001, entitled "Light-Emitting Diode Based Products;"

U.S. Patent Application Serial No. 09/716,819, filed November 20, 2000, entitled "Systems and Methods for Generating and Modulating Illumination Conditions;"

U.S. Patent Application Serial No. 09/675,419, filed September 29, 2000, entitled "Systems and Methods for Calibrating Light Output by Light-Emitting Diodes;"

U.S. Patent Application Serial No. 09/870,418, filed May 30, 2001, entitled "A Method and Apparatus for Authoring and Playing Back Lighting Sequences;"

U.S. Patent Application Serial No. 10/045,629, filed October 25, 2001, entitled "Methods and Apparatus for Controlling Illumination;"

U.S. Patent Application Serial No. 10/158,579, filed May 30, 2002, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

U.S. Patent Application Serial No. 10/325,635, filed December 19, 2002, entitled "Controlled Lighting Methods and Apparatus;" and

U.S. Patent Application Serial No. 10/360,594, filed February 6, 2003, entitled "Controlled Lighting Methods and Apparatus."

It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter disclosed herein.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 shows a configuration of a light system with a lighting unit, power facility and control facility.

Fig. 2 shows a configuration of system elements for a light system.

Fig. 3 shows configurations for solid state illuminators.

Fig. 4 shows a lighting system with an optical facility.

Fig. 5 shows a miniaturized lighting system.

Fig. 6 shows a flexible band lighting system.

Fig. 7 shows a spherical lighting system.

Fig. 8 shows a sponge lighting system.

Fig. 9 shows a tool with an integrated lighting system.

Fig. 10 shows a lighting system with an off-axis facility for modifying light from a lighting system.

Fig. 11 shows a mechanical interface for attaching a lighting unit to an object.

Fig. 12 shows fasteners for attaching lighting units to a platform.

Fig. 13 shows a chromaticity diagram depicting a gamut of colors that can be produced by a plurality of light sources.

Fig. 14 shows a flow diagram for a lighting method.

Fig. 15 shows a configuration for a management system for lighting units.

Fig. 16 shows modules of a light system manager facility.

Fig. 17 shows a light system management facility including a network configuration for a plurality of light sources.

Fig. 18 shows a configuration for a system for transmitting control instructions for lighting systems.

Fig. 19 shows an operating environment for a surgical lighting system.

Fig. 20 shows a lighting unit integrated into a surgical retractor.

Fig. 21 shows a lighting unit with a positioning system.

Fig. 22 shows a schematic diagram for a controller for a lighting unit with a positioning system.

Fig. 23 shows a handheld lighting unit for illuminating a material.

Fig. 24 shows a lighting unit integrated with a cauterizing facility.

Fig. 25 shows an endoscopic lighting unit for intranasal insertion.

Fig. 26 shows a lighting unit integrated with a surgical headband.

Fig. 27 shows a lighting unit integrated into surgical loupes.

Fig. 28 shows a lighting unit for lighting a medical condition such as a lesion.

DETAILED DESCRIPTION

Referring to Fig. 1, in a lighting system 100 a lighting unit 102 is controlled by a control facility 3500. In embodiments, the control facility 3500 controls the intensity, color, saturation, color temperature, on-off state, brightness, or other feature of light that is produced by the lighting unit 102. The lighting unit 102 can draw power from a power facility 1800. The lighting unit 102 can include a light source 300, which in embodiments is a solid-state light source, such as a semiconductor-based light source, such as light emitting diode, or LED.

Referring to Fig. 2, the system 100 can be a solid-state lighting system and can include the lighting unit 102 as well as a wide variety of optional control facilities 3500.

In embodiments, the system 100 may include an electrical facility 202 for powering and controlling electrical input to the light sources 300, which may include drive hardware 3802, such as circuits and similar elements, and the power facility 1800.

In embodiments the system can include a mechanical interface 3200 that allows the lighting unit 102 to mechanically connect to other portions of the system 100, or to

external components, products, lighting units, housings, systems, hardware, or other items.

The lighting unit 102 may have a primary optical facility 1700, such as a lens, mirror, or other optical facility for shaping beams of light that exit the light source, such as photons exiting the semiconductor in an LED package

The system 100 may include an optional secondary optical facility 400, which may diffuse, spread, focus, filter, diffract, reflect, guide or otherwise affect light coming from a light source 300. The secondary optical facility 400 may include one or many elements.

In embodiments, the light sources 300 may be disposed on a support structure, such as a board 204. The board 204 may be a circuit board or similar facility suitable for holding light sources 300 as well as electrical components, such as components used in the electrical facility 202.

In embodiments the system 100 may include a thermal facility 2500, such as a heat-conductive plate, metal plate, gap pad, liquid heat-conducting material, potting facility, fan, vent, or other facility for removing heat from the light sources 300.

The system 100 may optionally include a housing 800, which in embodiments may hold the board 204, the electrical facility 202, the mechanical interface 3200, and the thermal facility 2500. In some embodiments, no housing 800 is present.

In embodiments the system 100 is a standalone system with an on-board control facility 3500. The system 100 can include a processor 3600 for processing data to accept control instructions and to control the drive hardware 3802.

In embodiments the system 100 can respond to control of a user interface 4908, which may provide control directly to the lighting unit 102, such as through a switch,

dial, button, dipswitch, slide mechanism, or similar facility or may provide control through another facility, such as a network interface 4902, a light system manager 5000, or other facility.

The system 100 can include a data storage facility 3700, such as memory. In a standalone embodiment the data storage facility 3700 may be memory, such as random access memory. In other embodiments the data storage facility 3700 may include any other facility for storing and retrieving data.

The system 100 can produce effects 9200, such as illumination effects 9300 that illuminate a subject 9900 and direct view effects 9400 where the viewer is intended to view the light sources 300 or the secondary optical facility 400 directly, in contrast to viewing the illumination produced by the light sources 300, as in illumination effects 9300. Effects can be static and dynamic, including changes in color, color-temperature, intensity, hue, saturation and other features of the light produced by the light sources 300. Effects from lighting units 102 can be coordinated with effects from other systems, including other lighting units 102.

The system 100 can be disposed in a wide variety of environments 9600, where effects 9200 interact with aspects of the environments 9600, such as subjects 9900, objects, features, materials, systems, colors or other characteristics of the environments. Environments 9600 can include interior and exterior environments, architectural and entertainment environments, underwater environments, commercial environment, industrial environments, recreational environments, home environments, transportation environments and many others.

Subjects 9900 can include a wide range of subjects 9900, ranging from objects such as walls, floors and ceilings to alcoves, pools, spas, fountains, curtains, people, signs, logos, buildings, rooms, objects of art and photographic subjects, among many others.

While embodiments of a control facility 3500 may be as simple as a single processor 3600, data storage facility 3700 and drive hardware 3802, in other embodiments more complex control facilities 3500 are provided. Control facilities may include more complex drive facilities 3800, including various forms of drive hardware 3802, such as switches, current sinks, voltage regulators, and complex circuits, as well as various methods of driving 4300, including modulation techniques such as pulse-width-modulation, pulse-amplitude-modulation, combined modulation techniques, table-based modulation techniques, analog modulation techniques, and constant current techniques. In embodiments a control facility 3500 may include a combined power/data protocol 4800 for controlling light sources 300 in response to data delivered over power lines.

A control facility 3500 may include a control interface 4900, which may include a physical interface 4904 for delivering data to the lighting unit 102. The control interface 4900 may also include a computer facility, such as a light system manager 5000 for managing the delivery of control signals, such as for complex shows and effects 9200 to lighting units 102, including large numbers of lighting units 102 deployed in complex geometric configurations over large distances.

The control interface 4900 may include a network interface 4902, such as for handling network signals according to any desired network protocol, such as DMX, Ethernet, TCP/IP, DALI, 802.11 and other wireless protocols, and linear addressing protocols, among many others. In embodiments the network interface 4902 may support multiple protocols for the same lighting unit 102.

In embodiments involving complex control, the physical data interface 4904 may include suitable hardware for handling data transmissions, such as USB ports, serial ports, Ethernet facilities, wires, routers, switches, hubs, access points, buses, multi-function ports, intelligent sockets, intelligent cables, flash and USB memory devices, file players, and other facilities for handling data transfers.

In embodiments the control facility 3500 may include an addressing facility 6600, such as for providing an identifier or address to one or more lighting units 102. Many kinds of addressing facility 6600 may be used, including facilities for providing network addresses, dipswitches, bar codes, sensors, cameras, and many others.

In embodiments the control facility 3500 may include an authoring facility 7400 for authoring effects 9200, including complex shows, static and dynamic effects. The authoring facility 7400 may be associated with the light system manager 5000, such as to facilitate delivery of control signals for complex shows and effects over a network interface 4900 to one or more lighting units 102. The authoring facility 7400 may include a geometric authoring facility, an interface for designing light shows, an object-oriented authoring facility, an animation facility, or any of a variety of other facilities for authoring shows and effects.

In embodiments the control facility 3500 may take input from a signal sources 8400, such as a sensor 8402, an information source, a light system manager 5000, a user interface 4908, a network interface 4900, a physical data interface 4904, an external system 8800, or any other source capable of producing a signal.

In embodiments the control facility 3500 may respond to an external system 8800. The external system 8800 may be a computer system, an automation system, a security system, an entertainment system, an audio system, a video system, a personal computer, a laptop computer, a handheld computer, or any of a wide variety of other systems that are capable of generating control signals.

Referring to Fig. 3, the lighting unit 102 may be any kind of lighting unit 102 that is capable of responding to control, but in embodiments the lighting unit 102 includes a light source 300 that is a solid-state light source, such as a semiconductor-based light source, such as a light emitting diode, or LED. Lighting units 102 can include LEDs that produce a single color or wavelength of light, or LEDs that produce different colors or

wavelengths, including red, green, blue, white, orange, amber, ultraviolet, infrared, purple or any other wavelength of light.

Lighting units 102 can include other light sources, such as organic LEDS, or OLEDs, light emitting polymers, crystallo-luminescent lighting units, lighting units that employ phosphors, luminescent polymers and other sources. In other embodiments, lighting units 102 may include incandescent sources, halogen sources, metal halide sources, fluorescent sources, compact fluorescent sources and others.

Referring still to Fig. 3, the sources 300 can be point sources or can be arranged in many different configurations 302, such as a linear configuration 306, a circular configuration 308, an oval configuration 304, a curvilinear configuration, or any other geometric configuration, including two-dimensional and three-dimensional configurations. The sources 300 can also be mixed, including sources 300 of varying wavelength, intensity, power, quality, light output, efficiency, efficacy or other characteristics. In embodiments sources 300 for different lighting units 102 are consistently mixed to provide consistent light output for different lighting units 102. In embodiments the sources are mixed 300 to allow light of different colors or color temperatures, including color temperatures of white. Various mixtures of sources 300 can produce substantially white light, such as mixtures of red, green and blue LEDs, single white sources 300, two white sources of varying characteristics, three white sources of varying characteristics, or four or more white sources of varying characteristics. One or more white source can be mixed with, for example, an amber or red source to provide a warm white light or with a blue source to produce a cool white light.

Sources 300 may be constructed and arranged to produce a wide range of variable color radiation. For example, the source 300 may be particularly arranged such that the processor-controlled variable intensity light generated by two or more of the light sources combines to produce a mixed colored light (including essentially white light having a variety of color temperatures). In particular, the color (or color temperature) of

the mixed colored light may be varied by varying one or more of the respective intensities of the light sources or the apparent intensities, such as using a duty cycle in a pulse width modulation technique. Combinations of LEDs with other mechanisms that affect light characteristics, such as phosphors, are also encompassed herein.

Any combination of LED colors can produce a gamut of colors, whether the LEDs are red, green, blue, amber, white, orange, UV, or other colors. The various embodiments described throughout this specification encompass all possible combinations of LEDs in lighting units 102, so that light of varying color, intensity, saturation and color temperature can be produced on demand under control of a control facility 3500.

Although mixtures of red, green and blue have been proposed for light due to their ability to create a wide gamut of additively mixed colors, the general color quality or color rendering capability of such systems are not ideal for all applications. This is primarily due to the narrow bandwidth of current red, green and blue emitters. However, wider band sources do make possible good color rendering, as measured, for example, by the standard CRI index. In some cases this may require LED spectral outputs that are not currently available. However, it is known that wider-band sources of light will become available, and such wider-band sources are encompassed as sources for lighting units 102 described herein.

Additionally, the addition of white LEDs (typically produced through a blue or UV LED plus a phosphor mechanism) does give a 'better' white, but it still can be limiting in the color temperature that is controllable or selectable from such sources.

The addition of white to a red, green and blue mixture may not increase the gamut of available colors, but it can add a broader-band source to the mixture. The addition of an amber source to this mixture can improve the color still further by 'filling in' the gamut as well.

Combinations of light sources 300 can help fill in the visible spectrum to faithfully reproduce desirable spectrums of lights. These include broad daylight equivalents or more discrete waveforms corresponding to other light sources or desirable light properties. Desirable properties include the ability to remove pieces of the spectrum for reasons that may include environments where certain wavelengths are absorbed or attenuated. Water, for example tends to absorb and attenuate most non-blue and non-green colors of light, so underwater applications may benefit from lights that combine blue and green sources 300.

Amber and white light sources can offer a color temperature selectable white source, wherein the color temperature of generated light can be selected along the black body curve by a line joining the chromaticity coordinates of the two sources. The color temperature selection is useful for specifying particular color temperature values for the lighting source.

Orange is another color whose spectral properties in combination with a white LED-based light source can be used to provide a controllable color temperature light from a lighting unit 102.

As used herein for purposes of the present disclosure, the term "LED" should be understood to include any light emitting diode or other type of carrier injection / junction-based system that is capable of generating radiation in response to an electric signal. Thus, the term LED includes, but is not limited to, various semiconductor-based structures that emit light in response to current, light emitting polymers, light-emitting strips, electro-luminescent strips, and the like.

In particular, the term LED refers to light emitting diodes of all types (including semi-conductor and organic light emitting diodes) that may be configured to generate radiation in one or more of the infrared spectrum, ultraviolet spectrum, and various portions of the visible spectrum (generally including radiation wavelengths from approximately 400 nanometers to approximately 700 nanometers). Some examples of LEDs include, but are not limited to, various types of infrared LEDs, ultraviolet LEDs,

red LEDs, blue LEDs, green LEDs, yellow LEDs, amber LEDs, orange LEDs, and white LEDs (discussed further below). It also should be appreciated that LEDs may be configured to generate radiation having various bandwidths for a given spectrum (e.g., narrow bandwidth, broad bandwidth).

For example, one implementation of an LED configured to generate essentially white light (e.g., a white LED) may include a number of dies which respectively emit different spectrums of luminescence that, in combination, mix to form essentially white light. In another implementation, a white light LED may be associated with a phosphor material that converts luminescence having a first spectrum to a different second spectrum. In one example of this implementation, luminescence having a relatively short wavelength and narrow bandwidth spectrum "pumps" the phosphor material, which in turn radiates longer wavelength radiation having a somewhat broader spectrum.

It should also be understood that the term LED does not limit the physical and/or electrical package type of an LED. For example, as discussed above, an LED may refer to a single light emitting device having multiple dies that are configured to respectively emit different spectrums of radiation (e.g., that may or may not be individually controllable). Also, an LED may be associated with a phosphor that is considered as an integral part of the LED (e.g., some types of white LEDs). In general, the term LED may refer to packaged LEDs, non-packaged LEDs, surface mount LEDs, chip-on-board LEDs, radial package LEDs, power package LEDs, LEDs including some type of encasement and/or optical element (e.g., a diffusing lens), etc.

The term "light source" should be understood to refer to any one or more of a variety of radiation sources, including, but not limited to, LED-based sources as defined above, incandescent sources (e.g., filament lamps, halogen lamps), fluorescent sources, phosphorescent sources, high-intensity discharge sources (e.g., sodium vapor, mercury vapor, and metal halide lamps), lasers, other types of luminescent sources, electro-lumiscent sources, pyro-luminescent sources (e.g., flames), candle-luminescent sources (e.g., gas mantles, carbon arc radiation sources), photo-luminescent sources (e.g.,

gaseous discharge sources), cathode luminescent sources using electronic satiation, galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources , sonoluminescent sources, radioluminescent sources, and luminescent polymers.

A given light source may be configured to generate electromagnetic radiation within the visible spectrum, outside the visible spectrum, or a combination of both. Hence, the terms "light" and "radiation" are used interchangeably herein. Additionally, a light source may include as an integral component one or more filters (e.g., color filters), lenses, or other optical components. Also, it should be understood that light sources may be configured for a variety of applications, including, but not limited to, indication and/or illumination. An "illumination source" is a light source that is particularly configured to generate radiation having a sufficient intensity to effectively illuminate an interior or exterior space.

The term "spectrum" should be understood to refer to any one or more frequencies (or wavelengths) of radiation produced by one or more light sources. Accordingly, the term "spectrum" refers to frequencies (or wavelengths) not only in the visible range, but also frequencies (or wavelengths) in the infrared, ultraviolet, and other areas of the overall electromagnetic spectrum. Also, a given spectrum may have a relatively narrow bandwidth (essentially few frequency or wavelength components) or a relatively wide bandwidth (several frequency or wavelength components having various relative strengths). It should also be appreciated that a given spectrum may be the result of a mixing of two or more other spectrums (e.g., mixing radiation respectively emitted from multiple light sources).

For purposes of this disclosure, the term "color" is used interchangeably with the term "spectrum." However, the term "color" generally is used to refer primarily to a property of radiation that is perceivable by an observer (although this usage is not intended to limit the scope of this term). Accordingly, the terms "different colors" implicitly refer to different spectrums having different wavelength components and/or

bandwidths. It also should be appreciated that the term "color" may be used in connection with both white and non-white light.

The term "color temperature" generally is used herein in connection with white light, although this usage is not intended to limit the scope of this term. Color temperature essentially refers to a particular color content or shade (e.g., reddish, bluish) of white light. The color temperature of a given radiation sample conventionally is characterized according to the temperature in degrees Kelvin (K) of a black body radiator that radiates essentially the same spectrum as the radiation sample in question. The color temperature of white light generally falls within a range of from approximately 700 degrees K (generally considered the first visible to the human eye) to over 10,000 degrees K.

Lower color temperatures generally indicate white light having a more significant red component or a "warmer feel," while higher color temperatures generally indicate white light having a more significant blue component or a "cooler feel." By way of example, a wood burning fire has a color temperature of approximately 1,800 degrees K, a conventional incandescent bulb has a color temperature of approximately 2848 degrees K, early morning daylight has a color temperature of approximately 3,000 degrees K, and overcast midday skies have a color temperature of approximately 10,000 degrees K. A color image viewed under white light having a color temperature of approximately 3,000 degree K has a relatively reddish tone, whereas the same color image viewed under white light having a color temperature of approximately 10,000 degrees K has a relatively bluish tone.

Illuminators may be selected so as to produce a desired level of output, such as a desired total number of lumens of output, such as to make a lighting unit 102 consistent with or comparable to another lighting unit 102, which might be a semiconductor illuminator or might be another type of lighting unit, such as an incandescent, fluorescent, halogen or other light source, such as if a designer or architect wishes to fit semiconductor-based lighting units 102 into installations that use such traditional units.

The number and type of semiconductor illuminators can be selected to produce the desired lumens of output, such as by selecting some number of one-watt, five-watt, power package or other LEDs. In embodiments two or three LEDs are chosen. In other embodiments any number of LEDs, such as six, nine, twenty, thirty, fifty, one hundred, three hundred or more LEDs can bechosen.

Referring to Fig. 4, a system 100 can include a secondary optical facility 400 to optically process the radiation generated by the light sources 300, such as to change one or both of a spatial distribution and a propagation direction of the generated radiation. In particular, one or more optical facilities may be configured to change a diffusion angle of the generated radiation. One or more optical facilities 400 may be particularly configured to variably change one or both of a spatial distribution and a propagation direction of the generated radiation (e.g., in response to some electrical and/or mechanical stimulus). An actuator 404, such as under control of a control facility 3500, can control an optical facility 400 to produce different optical effects.

An optical facility 400 may be a diffuse.. A diffuser may absorb and scatter light from a source 300, such as to produce a glowing effect in the diffuser. Diffusers can take many different shapes, such as tubes, cylinders, spheres, pyramids, cubes, tiles, panels, screens, doughnut shapes, V-shapes, T-shapes, U-shapes, junctions, connectors, linear shapes, curves, circles, squares, rectangles, geometric solids, irregular shapes, shapes that resemble objects found in nature, and any other shape. Diffusers may be made of plastics, polymers, hydrocarbons, coated materials, glass materials, crystals, micro-lens arrays, fiber optics, or a wide range of other materials.

Other examples of optical facilities 400 include, but are not limited to, reflectors, lenses, reflective materials, refractive materials, translucent materials, filters, mirrors, spinning mirrors, dielectric mirrors, Bragg cells, MEMs, acousto-optic modulators, crystals, gratings and fiber optics. The optical facility 400 also may include a

phosphorescent material, luminescent material, or other material capable of responding to or interacting with the generated radiation.

Variable optics can provide discrete or continuous adjustment of beam spread or angle or simply the profile of the light beam emitted from a fixture. Properties can include, but are not limited to, adjusting the profile for surfaces that vary in distance from the fixture, such as wall washing fixtures. In various embodiments, the variable nature of the optic can be manually adjusted, adjusted by motion control or automatically be controlled dynamically.

Actuation of variable optics can be through any kind of actuator, such as an electric motor, piezoelectric device, thermal actuator, motor, gyro, servo, lever, gear, gear system, screw drive, drive mechanism, flywheel, wheel, or one of many well-known techniques for motion control. Manual control can be through an adjustment mechanism that varies the relative geometry of lens, diffusion materials, reflecting surfaces or refracting elements. The adjustment mechanism may use a sliding element, a lever, screws, or other simple mechanical devices or combinations of simple mechanical devices. A manual adjustment or motion control adjustment may allow the flexing of optical surfaces to bend and shape the light passed through the system or reflected or refracted by the optical system.

Actuation can also be through an electromagnetic motor or one of many actuation materials and devices. Optical facilities 400 can also include other actuators, such as piezo-electric devices, MEMS devices, thermal actuators, processors, and many other forms of actuators.

A wide range of optical facilities 400 can be used to control light. Such devices as Bragg cells or holographic films can be used as optical facilities 400 to vary the output of a fixture. A Bragg cell or acoustic-optic modulator can provide for the movement of light with no other moving mechanisms. The combination of controlling the color (hue, saturation and value) as well as the form of the light beam brings a tremendous amount of operative control to a light source. The use of polarizing films can be used to reduce

glare and allow the illumination and viewing of objects that present specular surfaces, which typically are difficult to view. Moving lenses and shaped non-imaging surfaces can provide optical paths to guide and shape light.

In other embodiments, fluid-filled surfaces and shapes can be manipulated to provide an optical path. In combination with lighting units, such shapes can provide varying optical properties across the surface and volume of the fluid-filled material. The fluid-filled material can also provide a thermal dissipation mechanism for the light-emitting elements. The fluid can be water, polymers, silicone or other transparent or translucent liquid or a gas of any type and mixture with desirable optical or thermal properties.

In other embodiments, gelled, filled shapes can be used in conjunction with light sources to evenly illuminate said shapes. Light propagation and diffusion is accomplished through the scattering of light through the shape.

The terms "lighting unit," "luminaire" and "lighting fixture" are used herein to refer to an apparatus including one or more light sources 300. A given lighting unit 102 may have any one of a variety of mounting arrangements for the light source(s) in a variety of housings 800.

Referring to Fig. 8, housings 800 may include a housing for an architectural lighting fixture, such as a wall-washing fixture. Housings may be square, rectangular, circular, cylindrical, or linear. Housings 800 may be configured to resemble retrofit bulbs, fluorescent bulbs, incandescent bulbs, halogen lamps, high-intensity discharge lamps, or other kinds of bulbs and lamps. Housings 800 may be configured as tiles or panels, such as for wall-hangings, walls, ceiling tiles, or floor tiles. Housings 800 may be configured to resemble neon lights, such as for signs, logos, or decorative purposes. Housings 800 may be configured to highlight architectural features, such as lines of a building, room or architectural feature.

Housings 800 may be configured for various industrial applications, such as medical lighting and surgical lighting.

Additionally, one or more lighting units similar to that described in connection with Fig. 2 may be implemented in a variety of products including, but not limited to, various forms of light modules or bulbs having various shapes and electrical/mechanical coupling arrangements (including replacement or "retrofit" modules or bulbs adapted for use in conventional sockets or fixtures), as well as a variety of specialized retrofit lighting units, such as for medical or surgical lighting.

Housings 800 can take various shapes, such as one that resembles a point source, such as a circle or oval. Such a point source can be located in a conventional lighting fixture, such as lamp or a cylindrical fixture. Lighting units 102 can be configured in substantially linear arrangements, either by positioning point sources in a line, or by disposing light sources substantially in a line on a board located in a substantially linear housing, such as a cylindrical housing. A linear lighting unit can be placed end-to-end with other linear elements or elements of other shapes to produce longer linear lighting systems comprised of multiple lighting units 102 in various shapes. A housing can be curved to form a curvilinear lighting unit. Similarly, junctions can be created with branches, "Ts," or "Ys" to created a branched lighting unit. A bent lighting unit can include one or more "V" elements. Combinations of various configurations of point source, linear, curvilinear, branched and bent lighting units 102 can be used to create any shape of lighting system, such as one shaped to resemble a letter, number, symbol, logo, object, structure, or the like.

Housings 800 can include or be combined to produce three-dimensional configurations, such as made from a plurality of lighting units 102. Linear lighting units 102 can be used to create three-dimensional structures and objects, or to outline existing structures and objects when disposed along the lines of such structures and objects. Many different displays, objects, structures, and works of art can be created using linear lighting units as a medium. Examples include pyramid configurations, building outlines

and two-dimensional arrays. Linear units in two-dimensional arrays can be controlled to act as pixels in a lighting show.

In embodiments the housing 800 may be a housing for an architectural, theatrical, or entertainment lighting fixture, luminaire, lamp, system or other product. The housing 800 may be made of a metal, a plastic, a polymer, a ceramic material, glass, an alloy or another suitable material. The housing 800 may be cylindrical, hemispherical, rectangular, square, or another suitable shape. The size of the housing may range from very small to large diameters, depending on the nature of the lighting application. The housing 800 may be configured to resemble a conventional architectural lighting fixture, such as to facilitate installation in proximity to other fixtures, including those that use traditional lighting technologies such as incandescent, fluorescent, halogen, or the like. The housing 800 may be configured to resemble a lamp. The housing 800 may be configured as a spot light, a down light, an up light, a cove light, an alcove light, a sconce, a border light, a wall-washing fixture, an alcove light, an area light, a desk lamp, a chandelier, a ceiling fan light, a marker light, a theatrical light, a moving-head light, a pathway light, a cove light, a recessed light, a track light, a wall fixture, a ceiling fixture, a floor fixture, a circular fixture, a spherical fixture, a square fixture, a rectangular fixture, an accent light, a pendant, a parabolic fixture, a strip light, a soffit light, a valence light, a floodlight, an indirect lighting fixture, a direct lighting fixture, a flood light, a cable light, a swag light, a picture light, a portable luminaire, an island light, a torchiere, a boundary light, a flushor any other kind architectural or theatrical lighting fixture or luminaire.

Housings may also take appropriate shapes for various specialized, industrial, commercial or high performance lighting applications. For example, in an embodiment a miniature system, such as might be suitable for medical or surgical applications or other applications demanding very small light systems 100, can include a substantially flat light shape, such as round, square, triangular or rectangular shapes, as well as non-symmetric shapes such as tapered shapes. In many such embodiments, housing 800

could be generally described as a planar shape with some small amount of depth for components.

Referring to Fig. 5, the housing 800 can be small and round, such as about ten millimeters in diameter (and can be designed with the same or similar configuration at many different scales.) The housing 800 may include a power facility, a mounting facility and an optical facility. The housing 800 and optical facility can be made of metals or plastic materials suitable for medical or surgical use.

Referring to Fig. 6, housings 800 may also take the form of a flexible band 602, tape or ribbon to allow the user to conform the housing to particular shapes or cavities. Such a ribbon can be made in various lengths, widths and thicknesses to suit specific demands of applications that benefit from flexible housings 800, such as for shaping to fit body parts or cavities for surgical lighting applications. In flexible embodiments it may be advantageous to use a flexible thin-form battery 604, such as a polymer or "paper" battery, as a power facility 1800. The battery 604 or another flexible material can serve as a substrate onto which the light sources 300 can be disposed. The light sources 300 can be encapsulated by a substantially light-transmissive encapsulant 608. Flexible wires or other components can be disposed along the band 602 to provide power and data to the light sources 300.

Referring to Fig. 7, in embodiments a housing 800 may be configured as a sphere 702 or ball, so as to produce light in substantially all directions. The sphere or ball housing 800 may be provided with battery operation as a power facility, such as to allow the ball to be quickly tossed into areas where light is needed, such as in medical or surgical contexts, such as in body cavities during surgery. A ball housing 800 lighting system 100 can provide omni-directional light from a cool light source, one that can be placed near body tissue, unlike many traditional light sources. The ball housing 800 can be made of plastic or glass material that could be transparent for maximum light projection or diffuse to provide softer light output that is less subject to reflections. The ball housing 800 could be very small, such as the size of a marble or a golf ball, so that it

is easily managed in environments that require miniature light systems 100, or it could be very large, such as in art, architectural, and entertainment applications. Multiple balls can be used simultaneously to provide additional light. If it is desired to have directional light from a ball lighting system 100, then part of the ball can be made dark. The ball housing 800 has the additional advantage that it has no sharp edges, so that it is unlikely to cut body tissue during surgery in such applications.

In embodiments a lighting unit 102 may be embedded into a sponge 802, such as for a surgical application. The sponge 802 can be used in any surgical or medical application where absorption is required, while simultaneously supplying light to a work area, such as a body cavity.

Housings 800 can incorporate lighting units 102 into conventional objects, such as tools, utensils, or other objects. Referring to Fig. 9, a housing 800 may be shaped into a surgical tool 902, such as tweezers 910, a retractor 912, forceps or the like. A lighting unit 102 can be collocated at the end of a tool 902 and provide illumination to the working area of the tool. One of many advantages of this type of tool is the ability to directly illuminate the working area, avoiding the tendency of tools or the hands that use them to obscure the working area. Tools can have onboard batteries or include other power facilities as described herein. In embodiments the mechanical interface 3200 may connect light sources 300 to fiber bundles to create flexible lighting units 102. A lighting unit 102 can be configured to be incorporated directly in a tool 902, so that the fiber transports the light to another part of the tool 902. This would allow the light source 300 to be separated from the 'working' end of the tool but still provide the lighting unit 102 without external cabling and with only a short efficient length of fiber. An electro-luminescent panel can be used wherein the power is supplied via onboard power in the form of a battery or a cable or wire to an off board source.

Thus, housings 800 can be configured as tools, such as surgical tools 902, such as cutting instruments such as scalpels, knives, and scissors, including Metzenbaum, Nelson, suture, Jorgenson and Mayo devices; grasping, holding and clamping

instruments, such tissue forceps, towel clips, needle drivers, forceps (smooth, toothed, Bonney, Adson, Debakey and others), light clamps (Mosquito, Babcock, right angle, Hemostats, Allis and others), heavy clamps (Kocher, Phaneuf, Kelly, Heany and others), and needle holders (Heaney, straight and others); exposing instruments or retractors, such as malleable retractors and self-retaining devices, including Army-Navy, Richardson, Weitlander, Deaver, Balfour, Basket, Vein, Rake, Parker, Bookwalter, Iron Hand and others; electro-surgical pencils; cauterizing tools; suction tools; and any other kind of surgical tools 902.

In embodiments a retractor 912 is augmented with an attached or integrated light source 908, wherein the power and light is provided at one end of the tool and piped through a fiber optic cable to the far end of the tool for illumination purposes. The advantage of the fiber optic plane or even an electroluminescent device is the cool diffuse illumination that it provides. In other embodiments the light source 300 is an LED.

In one embodiment, the lighting unit 102 or a light source 300 of Figs. 1 and 2 may include and/or be coupled to a power facility 1800. In various aspects, examples of power facilities 1800 include, but are not limited to, AC power sources, DC power sources, batteries, solar-based power sources, thermoelectric or mechanical-based power sources and the like. Additionally, in one aspect, the power facility 1800 may include or be associated with one or more power conversion devices that convert power received by an external power source to a form suitable for operation of the lighting unit 102.

The methods and systems disclosed herein also include a variety of methods and systems for light control, including central controllers as well as lighting unit controllers. One grouping of lighting controls includes dimmer controls, including both wired and wireless dimmer control. Traditional dimmers can be used with lighting units 102, not just in the traditional way using voltage control or resistive load, but rather by using a processor to scale and control output by interpreting the levels of voltage. In combination with a style and interface that is familiar to most people because of the ubiquity of

dimmer switches, one aspect of the present specification allows the position of a dimmer switch (linear or rotary) to indicate color temperature or intensity through a power cycle control. That is, the mode can change with each on or off cycle. A special switch can allow multiple modes without having to turn off the lights. An example of a product that uses this technique is the Color Dial, available from Color Kinetics.

In other embodiments, with line voltage power supply integrated into LED systems, power line carrier (PLC) allows such systems to simplify further. Installing LED systems is complex and currently often require a power supply, data wiring and the installation of these devices so that they are not visible. For example, 10 pieces of linear alcove lights can require a device to deliver data (a control facility) and a power supply that must be installed and hidden. Additional costs are incurred by the use of these devices. To improve the efficiency of such a system, an LED fixture or line of fixtures can be made capable of being plugged into line voltage. An LED-based system that plugs directly into line voltage offers overall system cost savings and eases installation greatly. Such a system ties into existing power systems (120 or 220VAC), and the data can be separately wired or provided through wireless control (one of several standards IR, RF, acoustic etc).

A power facility 1800 may include a battery, such as a watch-style battery, such as Lithium, Alkaline, Silver-Zinc, Nickel-Cadmium, Nickel metal hydride, Lithium ion and others. The power facility 1800 may include a thin-form polymer battery that has the advantage of being very low profile and flexible, which can be useful for lighting unit configurations in flexible forms such as ribbons and tape. A power facility 1800 may also comprise a fuel cell, photovoltaic cell, solar cell or similar energy-producing facility. A power facility 1800 may be a super-capacitor, a large-value capacitor that can store much more energy than a conventional capacitor. Charging can be accomplished externally through electrical contacts and the lighting device can be reused. A power facility 1800 can include an inductive charging facility. An inductive charging surface can be brought in proximity to a lighting unit 102 to charge an onboard power source, allowing, for example, a housing 800 to be sealed to keep out moisture and contaminants.

Battery technologies typically generate power at specific voltage levels such as 1.2 or 1.5V DC. LEDs, however, typically require forward voltages ranging from around 2VDC to 3.2VDC. As a result batteries may be put in series to achieve the required voltage or a boost converter may be used to raise the voltage.

It is also possible to use natural energy sources as a power facility 1800, such as solar power, the body's own heat, mechanical power generation, the body's electrical field, wind power, water power, or the like.

While in many embodiments a lighting unit 102 may be coupled to a separate power supply that takes line voltage and adjusts it to provide inputs suitable for light sources 300 such as LEDs, a power facility 1800 may include an on-board power facility 1800, such that the power facility 1800 is integral to the lighting unit 102.

Semiconductor devices like LED light sources 300 can be damaged by heat; accordingly, a system 100 may include a thermal facility 2500 for removing heat from a lighting unit 102. The thermal facility 2500 may be any facility for managing the flow of heat, such as a convection facility 2700, such as a fan or similar mechanism for providing air flow to the lighting unit 102, a pump or similar facility for providing flow of a heat-conducting fluid, a vent for allowing flow of air, or any other kind of convection facility 2700. The thermal facility 2500 can also be a conduction facility 2600, such as a conducting plate or pad of metal, alloy, or other heat-conducting material, a gap pad between a board 204 bearing light sources 300 and another facility, a thermal conduction path between heat-producing elements such as light sources 300 and circuit elements, a thermal potting facility, such as a polymer for coating heat-producing elements to receive heat. The thermal facility 2500 may be a radiation facility 2800 for allowing heat to radiate away from a lighting unit 102. A fluid thermal facility 2900 can permit flow of a liquid or gas to carry heat away from a lighting unit 102. The fluid may be water, a chlorofluorocarbon, a coolant, or the like. In a preferred embodiment a conductive plate is aluminum or copper. In embodiments a thermal conduction path

conducts heat from a circuit board bearing light sources 300 to a housing 800, so that the housing 800 radiates heat away from the lighting unit 102.

In embodiments the mechanical interface is a socket interface 3400, such as to allow the lighting unit 102 to fit into any conventional type of socket, which in embodiments may be a socket equipped with a control facility 3500, i.e., a smart socket. In embodiments the smart socket may store data relating to preferences about how light should be emitted from a lighting unit 102 that is disposed in the socket, such as to shine a particular color temperature of white light, such as if a surgical operating room in which the socket is disposed is specified to receive light of that color temperature or other characteristic. The smart socket can be used to control light coming from lighting units 102 disposed in it according to the desires of the user.

Referring to Fig. 10, in embodiments, such as for a surgical light, a light source 300 can be configured with an off-axis mounting facility 1010. The embodiment can alternatively include a shade that selectively allows light to shine through in certain areas and not in others. These techniques can be used to reduce glare and light shining directly into the eyes of a user of the lighting unit 102. Snap-on lenses can be used atop the light-emitting portion to allow for a much wider selection of light patterns and optical needs. In embodiments a disk-shaped light source 300 emits light in one off-axis direction. The light can then be rotated about the center axis to direct the light in a desired direction. The device may be simply picked up, rotated, and placed back down using the fastening means such as magnetic or clamp (see below for more fastening options) or may simply incorporate a rotational mechanism.

Referring to Fig. 11, a mechanical interface 3200 may be provided for connecting a lighting unit 102 or light source 300 mechanically to a platform, housing 800, mounting, board, other lighting unit 102, or other product or system. In embodiments the mechanical interface 3200 may be a modular interface 3202 for removeably and replaceably connecting a lighting unit 102 to another lighting unit 102 or to a board 204. The board 204 may comprise a lighting unit 102, or it may comprise a power facility for

a lighting unit 102. The modular interface may, for example, be a clip 1110 for connecting the lighting unit 102 to a chart or similar object in a medical or surgical environment. The interface 3200 may include a clamp 1112 or a fastener 1114, such as a screw, for connecting the lighting unit 102 to an object.

A mechanical interface 3200 may include facilities for fastening lighting units 102 or light sources 300, such as to platforms, tools, housing or the like. Embodiments include a magnetic fastening facility. In embodiments a lighting unit 102 is clamped or screwed into a tool or instrument. For example, a screw-type clamp 1114 can be used to attach a lighting unit 102 to another surface. A toggle-type clamp can be used, such as De-Sta-Co style clamps as used in the surgical field. A clip or snap-on facility can be used to attach a lighting unit 102 and allow flexing elements. A flexible clip can be added to the back of a lighting device 102 to make it easy to attach to another surface. A spring-clip, similar to a binder clip, can be attached to the back of a lighting unit 102. A flexing element can provide friction when placed on another surface. Fasteners can include a spring-hinge mechanism, string, wire, Ty-wraps, hook and loop fastener 1212, adhesives or the like.

Referring to Fig. 12, medical and surgical fastening materials include bone wax 1210; a beeswax compound (sometimes mixed with Vaseline), which can be hand, molded, and can also be used for holding the lighting device 102. The exterior of the lighting device 102 can be textured to provide grip and holding power to facilitate the fastening. Surgical tapes, such as DuoPlas from Sterion, are another example of materials that can be used to fasten the light to tools, instruments, and drapes or directly to the patient.

A control facility 3500 may produce a signal for instructing a light system 100 to produce a desired mixed light output. The signal can be a remote control. The signal can be provided by a network. The signal can use a data protocol, such as the DMX protocol.

In embodiments the control facility 3500 is a processor 3600. “Processor” or “controller” describes various apparatus relating to the operation of one or more light sources. A processor or controller can be implemented in numerous ways, such as with dedicated hardware, using one or more microprocessors that are programmed using software (e.g., microcode or firmware) to perform the various functions discussed herein, or as a combination of dedicated hardware to perform some functions and programmed microprocessors and associated circuitry to perform other functions.

In various implementations, a processor or controller may be associated with one or more storage media (generically referred to herein as “memory,” e.g., volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM, floppy disks, compact disks, optical disks, magnetic tape, etc.). In some implementations, the storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform at least some of the functions discussed herein. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller so as to implement various aspects of the present invention discussed herein. The terms “program” or “computer program” are used herein in a generic sense to refer to any type of computer code (e.g., software or microcode) that can be employed to program one or more processors or controllers, including by retrieval of stored sequences of instructions.

In particular, in a networked lighting system environment, as discussed in greater detail further below (e.g., in connection with Fig. 2), as data is communicated via the network, the processor 3600 of each lighting unit coupled to the network may be configured to be responsive to particular data (e.g., lighting control commands) that pertain to it (e.g., in some cases, as dictated by the respective identifiers of the networked lighting units). Once a given processor identifies particular data intended for it, it may read the data and, for example, change the lighting conditions produced by its light sources according to the received data (e.g., by generating appropriate control signals to

the light sources). In one aspect, the data facility of each lighting unit 102 coupled to the network may be loaded, for example, with a table of lighting control signals that correspond with data the processor 3600 receives. Once the processor 3600 receives data from the network, the processor may consult the table to select the control signals that correspond to the received data, and control the light sources of the lighting unit accordingly.

In one aspect of this embodiment, the processor 3600 of a given lighting unit, whether or not coupled to a network, may be configured to interpret lighting instructions/data that are received in a DMX protocol (as discussed, for example, in U.S. Patents 6,016,038 and 6,211,626), which is a lighting command protocol conventionally employed in the lighting industry for some programmable lighting applications. However, it should be appreciated that lighting units suitable for purposes of the present invention are not limited in this respect, as lighting units according to various embodiments may be configured to be responsive to other types of communication protocols so as to control their respective light sources. Protocols may be used that are particular to the environment of the lighting system 100, such as protocols used for medical or surgical environments, such as protocols used in a hospital network, such as Ethernet protocols or other protocols.

In other embodiments the processor 3600 may be an application specific integrated circuit, such as one configured to respond to instructions according to a protocol, such as the DMX protocol, Ethernet protocols, or serial addressing protocols where each ASIC responds to control instructions directed to it, based on the position of the ASIC in a string of similar ASICs.

In embodiments the data storage facility 3700 stores information relating to control of a lighting unit 102. For example, the data storage facility may be memory employed to store one or more lighting programs for execution by the processor 3600 (e.g., to generate one or more control signals for the light sources), as well as various types of data useful for generating variable color radiation (e.g., calibration information,

discussed further below). The memory also may store one or more particular identifiers (e.g., a serial number, an address, etc.) that may be used either locally or on a system level to identify the lighting unit 102. In various embodiments, such identifiers may be pre-programmed by a manufacturer, for example, and may be either alterable or non-alterable thereafter (e.g., via some type of user interface located on the lighting unit, via one or more data or control signals received by the lighting unit, etc.). Alternatively, such identifiers may be determined at the time of initial use of the lighting unit in the field, and again may be alterable or non-alterable thereafter. The data storage facility 3700 may also be a disk, diskette, compact disk, random access memory, read only memory, SRAM, DRAM, database, data mart, data repository, cache, queue, or other facility for storing data, such as control instructions for a control facility 3500 for a lighting unit 102. Data storage may occur locally with the lighting unit, in a socket or housing 800, or remotely, such as on a server or in a remote database. In embodiments the data storage facility 3700 comprises a player that stores shows that can be triggered through a simple interface.

The drive facility 3800 may include drive hardware 3802 for driving one or more light sources 300. In embodiments the drive hardware 3802 comprises a switch 3900, such as for turning on the current to a light source 300. In embodiments the switch 3900 is under control of a processor, so that the switch 3900 can turn on or off in response to control signals. In embodiments the switch turns on and off in rapid pulses, such as in pulse width modulation of the current to the LEDs, which results in changes in the apparent intensity of the LED, based on the percentage of the duty cycle of the pulse width modulation technique during which the switch is turned on.

The drive hardware 3802 may include a voltage regulator 4000 for controlling voltage to a light source, such as to vary the intensity of the light coming from the light source 300.

As shown in Fig. 1, the lighting unit 102 also may include the processor 3600 that is configured to output one or more control signals to drive the light sources 300 so as to generate various apparent intensities of light from the light sources. For example, in one implementation, the processor 3600 may be configured to output at least one control signal for each light source so as to independently control the intensity of light generated by each light source. Some examples of control signals that may be generated by the processor to control the light sources include, but are not limited to, pulse modulated signals, pulse width modulated signals (PWM), pulse amplitude modulated signals (PAM), pulse displacement modulated signals, analog control signals (e.g., current control signals, voltage control signals), combinations and/or modulations of the foregoing signals, or other control signals. In one aspect, the processor 3600 may control other dedicated circuitry that in turn controls the light sources so as to vary their respective intensities.

Lighting systems in accordance with this specification can operate LEDs in an efficient manner. Typical LED performance characteristics depend on the amount of current drawn by the LED. The optimal efficacy may be obtained at a lower current than the level where maximum brightness occurs. LEDs are typically driven well above their most efficient operating current to increase the brightness delivered by the LED while maintaining a reasonable life expectancy. As a result, increased efficacy can be provided when the maximum current value of the PWM signal may be variable. For example, if the desired light output is less than the maximum required output the current maximum and/or the PWM signal width may be reduced. This may result in pulse amplitude modulation (PAM), for example; however, the width and amplitude of the current used to drive the LED may be varied to optimize the LED performance. In an embodiment, a lighting system may also be adapted to provide only amplitude control of the current through the LED. While many of the embodiments provided herein describe the use of PWM and PAM to drive the LEDs, one skilled in the art would appreciate that there are many techniques to accomplish the LED control described herein and, as such, the scope of the present invention is not limited by any one control technique. In embodiments, it is possible to use other techniques, such as pulse frequency modulation (PFM), or pulse

displacement modulation (PDM), such as in combination with either or both of PWM and PAM.

Pulse width modulation (PWM) involves supplying a substantially constant current to the LEDs for particular periods of time. The shorter the time, or pulse-width, the less brightness an observer will observe in the resulting light. The human eye integrates the light it receives over a period of time and, even though the current through the LED may generate the same light level regardless of pulse duration, the eye will perceive short pulses as "dimmer" than longer pulses. The PWM technique is considered on of the preferred techniques for driving LEDs, although the present invention is not limited to such control techniques. When two or more colored LEDs are provided in a lighting system, the colors may be mixed and many variations of colors can be generated by changing the intensity, or perceived intensity, of the LEDs. In an embodiment, three colors of LEDs are presented (e.g., red, green and blue) and each of the colors is driven with PWM to vary its apparent intensity. This system allows for the generation of millions of colors (e.g., 16.7 million colors when 8-bit control is used on each of the PWM channels).

In an embodiment the LEDs are modulated with PWM as well as modulating the amplitude of the current driving the LEDs (Pulse Amplitude Modulation, or PAM). LED efficiency increases to a maximum followed by decreasing efficiency. Typically, LEDs are driven at a current level beyond its maximum efficiency to attain greater brightness while maintaining acceptable life expectancy. The objective is typically to maximize the light output from the LED while maintaining an acceptable lifetime. In an embodiment, the LEDs may be driven with a lower current maximum when lower intensities are desired. PWM may still be used, but the maximum current intensity may also be varied depending on the desired light output. For example, to decrease the intensity of the light output from a maximum operational point, the amplitude of the current may be decreased until the maximum efficiency is achieved. If further reductions in the LED brightness are desired the PWM activation may be reduced to reduce the apparent brightness.

One issue that may arise in connection with controlling multiple light sources 300 in the lighting unit 102, and controlling multiple lighting units 102 in a lighting system relates to potentially perceptible differences in light output between substantially similar light sources. For example, given two virtually identical light sources being driven by respective identical control signals, the actual intensity of light output by each light source may be perceptibly different. Such a difference in light output may be attributed to various factors including, for example, slight manufacturing differences between the light sources, normal wear and tear over time of the light sources that may differently alter the respective spectrums of the generated radiation, etc. For purposes of the present discussion, light sources for which a particular relationship between a control signal and resulting intensity are not known are referred to as "uncalibrated" light sources.

The use of one or more uncalibrated light sources in the lighting unit 102 may result in generation of light having an unpredictable, or "uncalibrated," color or color temperature. For example, consider a first lighting unit including a first uncalibrated red light source and a first uncalibrated blue light source, each controlled by a corresponding control signal having an adjustable parameter in a range of from zero to 255 (0-255). For purposes of this example, if the red control signal is set to zero, blue light is generated, whereas if the blue control signal is set to zero, red light is generated. However, if both control signals are varied from non-zero values, a variety of perceptibly different colors may be produced (e.g., in this example, at very least, many different shades of purple are possible). In particular, perhaps a particular desired color (e.g., lavender) is given by a red control signal having a value of 125 and a blue control signal having a value of 200.

Now consider a second lighting unit including a second uncalibrated red light source substantially similar to the first uncalibrated red light source of the first lighting unit, and a second uncalibrated blue light source substantially similar to the first uncalibrated blue light source of the first lighting unit. As discussed above, even if both of the uncalibrated red light sources are driven by respective identical control signals, the actual intensity of light output by each red light source may be perceptibly different. Similarly, even if both of the uncalibrated blue light sources are driven by respective

identical control signals, the actual intensity of light output by each blue light source may be perceptibly different.

With the foregoing in mind, it should be appreciated that if multiple uncalibrated light sources are used in combination in lighting units to produce a mixed colored light as discussed above, the observed color (or color temperature) of light produced by different lighting units under identical control conditions may be perceivably different. Specifically, consider again the "lavender" example above; the "first lavender" produced by the first lighting unit with a red control signal of 125 and a blue control signal of 200 indeed may be perceptibly different than a "second lavender" produced by the second lighting unit with a red control signal of 125 and a blue control signal of 200. More generally, the first and second lighting units generate uncalibrated colors by virtue of their uncalibrated light sources.

In view of the foregoing , in one embodiment of the present invention, the lighting unit 102 includes calibration means to facilitate the generation of light having a calibrated (e.g., predictable, reproducible) color at any given time. In one aspect, the calibration means is configured to adjust the light output of at least some light sources of the lighting unit so as to compensate for perceptible differences between similar light sources used in different lighting units.

For example, in one embodiment, the processor 3600 of the lighting unit 102 is configured to control one or more of the light sources 300 so as to output radiation at a calibrated intensity that substantially corresponds in a predetermined manner to a control signal for the light source(s). As a result of mixing radiation having different spectra and respective calibrated intensities, a calibrated color is produced. In one aspect of this embodiment, at least one calibration value for each light source is stored in the data facility 3700, and the processor 3600 is programmed to apply the respective calibration values to the control signals for the corresponding light sources so as to generate the calibrated intensities.

In one aspect of this embodiment, one or more calibration values may be determined once (e.g., during a lighting unit manufacturing/testing phase) and stored in memory 3700 for use by the processor 3600. In another aspect, the processor 3600 may be configured to derive one or more calibration values dynamically (e.g. from time to time) with the aid of one or more photosensors, for example. In various embodiments, the photosensor(s) may be one or more external components coupled to the lighting unit, or alternatively may be integrated as part of the lighting unit itself. A photosensor is one example of a signal source that may be integrated or otherwise associated with the lighting unit 102, and monitored by the processor 3600 in connection with the operation of the lighting unit. Other examples of such signal sources are discussed further below, in connection with the signal source 8400.

One exemplary method that may be implemented by the processor 102 to derive one or more calibration values includes applying a reference control signal to a light source, and measuring (e.g., via one or more photosensors) an intensity of radiation thus generated by the light source. The processor may be programmed to then make a comparison of the measured intensity and at least one reference value (e.g., representing an intensity that nominally would be expected in response to the reference control signal). Based on such a comparison, the processor may determine one or more calibration values for the light source. In particular, the processor may derive a calibration value such that, when applied to the reference control signal, the light source outputs radiation having an intensity that corresponds to the reference value (i.e., the "expected" intensity).

In various aspects, one calibration value may be derived for an entire range of control signal/output intensities for a given light source. Alternatively, multiple calibration values may be derived for a given light source (i.e., a number of calibration value "samples" may be obtained) that are respectively applied over different control signal/output intensity ranges, to approximate a nonlinear calibration function in a piecewise linear manner.

Referring to Fig. 13, a chromaticity diagram shows a range of colors that can be viewed by the human eye. The gamut 1314 defines the range of colors that it is possible to produce by additively mixing colors from multiple sources, such as three LEDs. Green LEDs produce light in a green region 1312, red LEDs produce light in a red region 1318 and blue LEDs produce light in a blue region 1312. Mixing these colors produces mixed light output, such as in the overlapping areas between the regions, including those for orange, purple and other mixed light colors. Mixing all three sources produces white light, such as along a black body curve 1310. Different mixtures produce different color temperatures of white light along or near the black body curve 1310. Typically an LED produces a narrow emission spectrum centered on a particular wavelength; i.e. a fixed color and a single point on the chromaticity diagram. Through the use of multiple LEDs and additive color mixing a variety of apparent colors can be produced.

In conventional LED-based light systems, constant current control is often preferred because of lifetime issues. Too much current can destroy an LED or curtail useful life. Too little current produces little light and is an inefficient or ineffective use of the LED.

The light output from a semiconductor illuminator may shift in wavelength as a result in changes in current. In general, the shift in output has been thought to be undesirable for most applications, since a stable light color is often preferred to an unstable one. Recent developments in LED light sources with higher power ratings (>100mA) have made it possible to operate LED systems effectively without supplying maximum current. Such operational ranges make it possible to provide LED-based lighting units 102 that have varying wavelength outputs as a function of current. Thus, different wavelengths of light can be provided by changing the current supplied to the LEDs to produce broader bandwidth colors (potentially covering an area, rather than just a point, in the chromaticity diagram), and to produce improved quality white light. This calibration technique not only changes the apparent intensity of the LEDs (reflecting the portion of the duty cycle of a pulse width modulation signal during which the LED is on as compared to the portion during which it is off), but also shifting the output wavelength or color. Current change can also broaden the narrow emission of the source, shifting the

saturation of the light source towards a broader spectrum source. Thus, current control of LEDs allows controlled shift of wavelength for both control and calibration purposes.

In the visible spectrum, roughly 400 to 700nm, the sensitivity of the eye varies according to wavelength. The sensitivity of the eye is least at the edges of that range and peaks at around 555nm in the middle of the green.

By rapidly changing the current and simultaneously adjusting the intensity via pulse width modulation, broader spectrum light source can be produced. This happens at sufficient speeds so there is no perceptible flicker. This rate is typically hundreds of Hertz or more. For example, PWM signals can vary both in current level and width. Narrower pulses offset increased current levels to produce the same or a similar intensity of light, but at slightly different wavelengths. As a result, depending on the adjustment of the two factors (on-time and current level) different light outputs could appear to be of similar brightness. The control is a balance between current level and the on time.

A spectrum from a single LED can be broadened by rapidly controlling the current and on-times to produce multiple shifted spectra. Thus, the original spectrum is shifted to a broader-spectrum by current shifts, while coordinated control of intensity is augmented by changes in PWM.

Current control can be provided with various embodiments, including feedback loops, such as using a light sensor as a signal source 8400, or a lookup table or similar facility that stores light wavelength and intensity output as a function of various combinations of pulse-width modulation and pulse amplitude modulation.

In embodiments, a lighting system can produce saturated colors for one purpose (entertainment, mood, effects), while for another purpose it can produce a good quality variable white light whose color temperature can be varied along with the spectral properties. Thus a single fixture can have narrow bandwidth light sources for multicolor light applications and then can change to a current and PWM control mode to get broad spectra to make good white light or non-white light with broader spectrum color characteristics. In addition, the control mode can be combined with various optical

facilities 400 described above to further control the light output from the system. In embodiments, the methods and systems can include a control loop and fast current sources to allow an operator to sweep about a broad spectrum. This could be done in a feed-forward system or with feedback to insure proper operation over a variety of conditions.

The control facility 4900 can switch between a current-control mode (which itself could be controlled by a PWM stream) and a separate PWM mode. Such a system can include simultaneous current control via PWM for wavelength and PWM control balanced to produce desired output intensity and color. Multiple such controllers can be used to create a light fixture that can vary in color (HSB) and spectrum based on the current and on-off control. The PWM signal can also be a PWM Digital-to-analog converter (DAC) such as those from Maxim and others. Note that the functions that correspond to particular values of output can be calibrated ahead of time by determining nominal values for the PWM signals and the resultant variations in the LED output. These can be stored in lookup tables or a function created that allows the mapping of desired values from LED control signals.

It may even be desirable to overdrive the LEDs. Although the currents would be above nominal operating parameters as described by the LED manufacturers, this can provide more light than normally feasible. The power source will also be drained faster, but the result can be a much brighter light source.

Modulation of lighting units 102 can include a data facility 3700, such as a look-up table, that determines the current delivered to light sources 300 based on predetermined values stored in the data facility 3700 based on inputs, which may include inputs from signal sources 8400, sensors, or the like.

It is also possible to drive light sources 300 with constant current, such as to produce a single color of light.

A control interface 4900 may be provided for a lighting unit 102. The interface can vary in complexity, ranging from having minimal control, such as "on-off" control and dimming, to much more extensive control, such as producing elaborate shows and effects using a graphical user interface for authoring them and using network systems to deliver the shows and effects to lighting units 102 deployed in complex geometries.

Referring to Fig. 14, a flow diagram 1450 shows steps for providing a medical tool with a lighting system 100. First, at a step 1452, a non-lighting tool is provided. Second, a lighting unit 102 is integrated into the tool. Finally, the user can control the light output of the tool by controlling the lighting unit 102.

Referring to Fig. 15, it is desirable to provide a light system manager 5000 to manage a plurality of lighting units 102 or other light systems.

Referring to Fig.16, a light system manager 5000 is provided, which may consist of a combination of hardware and software components. Included is a mapping facility 5002 for mapping the locations of a plurality of light systems. The mapping facility may use various techniques for discovering and mapping lights, such as described herein or as known to those of skill in the art. Also provided is a light system composer 5004 for composing one or more lighting shows that can be displayed on a light system. It should be noted that a show may include a single lighting effect, such as turning a light a particular desired color, a series of effects, or an elaborate show using many different light systems. Shows may be for utilitarian purposes (such as lighting a desired work area) as well as for aesthetic or entertainment purposes.

The authoring of the shows may be based on geometry and an object-oriented programming approach, such as the geometry of the light systems that are discovered and mapped using the mapping facility, according to various methods and systems disclosed herein or known in the art. Also provided is a light system engine, for playing lighting shows by executing code for lighting shows and delivering lighting control signals, such as to one or more lighting systems, or to related systems, such as

power/data systems, that govern lighting systems. Further details of the light system manager 5000, mapping facility 5002, light system composer 5004 and light system engine 5008 are provided herein.

The light system manager 5000, mapping facility 5002, light system composer 5004 and light system engine 5008 may be provided through a combination of computer hardware, telecommunications hardware and computer software components. The different components may be provided on a single computer system or distributed among separate computer systems.

Referring to Fig. 17, in an embodiment, the mapping facility 5002 and the light system composer 5004 are provided on an authoring computer 5010. The authoring computer 5010 may be a conventional computer, such as a personal computer. In embodiments the authoring computer 5010 includes conventional personal computer components, such as a graphical user interface, keyboard, operating system, memory, and communications capability. In embodiments the authoring computer 5010 operates with a development environment with a graphical user interface, such as a Windows environment. The authoring computer 5010 may be connected to a network, such as by any conventional communications connection, such as a wire, data connection, wireless connection, network card, bus, Ethernet connection, Firewire, 802.11 facility, Bluetooth, or other connection. In embodiments, such as in Fig. 17, the authoring computer 5010 is provided with an Ethernet connection, such as via an Ethernet switch 5102, so that it can communicate with other Ethernet-based devices, optionally including the light system engine 5008, a light system itself (enabled for receiving instructions from the authoring computer 5010), or a power/data supply (PDS) 1758 that supplies power and/or data to a light system. The mapping facility 5002 and the light system composer 5004 may comprise software applications running on the authoring computer 5010.

Referring still to Fig. 17, in an architecture for delivering control systems for complex shows to one or more light systems, shows that are composed using the authoring computer 5010 are delivered via an Ethernet connection through one or more

Ethernet switches to the light system engine 5008. The light system engine 5008 downloads the shows composed by the light system composer 5004 and plays them, generating lighting control signals for light systems. In embodiments, the lighting control signals are relayed by an Ethernet switch to one or more power/data supplies and are in turn relayed to light systems that are equipped to execute the instructions, such as by turning LEDs on or off, controlling their color or color temperature, changing their hue, intensity, or saturation, or the like. In embodiments the power/data supply may be programmed to receive lighting shows directly from the light system composer 5004. In embodiments a bridge may be programmed to convert signals from the format of the light system engine 5008 to a conventional format, such as DMX or DALI signals used for entertainment lighting.

Referring to Fig. 18, in embodiments the lighting shows composed using the light system composer 5004 are compiled into simple scripts that are embodied as XML documents. The XML documents can be transmitted rapidly over Ethernet connections. In embodiments, the XML documents are read by an XML parser 1802 of the light system engine 5008. Using XML documents to transmit lighting shows allows the combination of lighting shows with other types of programming instructions. For example, an XML document type definition may include not only XML instructions for a lighting show to be executed through the light system engine 5008, but also XML with instructions for another computer system 1850, such as another lighting system, a security system, an information system, a hospital network, an emergency broadcast network, a medical or surgical network, an operating room computer system, a sensor-feedback system, a sensor system, a browser, a network, a server, a wireless computer system, a building information technology system, or a communication system.

Thus, methods and systems provided herein include providing a light system engine for relaying control signals to a plurality of light systems, wherein the light system engine plays back shows. The light system engine 5008 may include a processor, a data facility, an operating system and a communication facility. The light system engine 5008 may be configured to communicate with a DALI or DMX lighting control

facility, a wireless control facility, an Ethernet facility, or the like. In embodiments, the light system engine communicates with a lighting control facility that operates with a serial communication protocol. In embodiments the lighting control facility is a power/data supply for a lighting unit 102.

In embodiments, the light system engine 5008 executes lighting shows or effects downloaded from the light system composer 5004. In embodiments the shows or effects are delivered as XML files from the light system composer 5004 to the light system engine 5008. In embodiment the shows are delivered to the light system engine over a network. In embodiments the shows are delivered over an Ethernet facility. In embodiments the shows are delivered over a wireless facility. In embodiments the shows are delivered over a Firewire facility. In embodiments shows are delivered over the Internet.

The simple triggering of shows can be through a button or even voice activation. For example, a surgeon or other medical staff could instruct a surgical light to turn a certain color by voice activation or by a wireless remote control.

In embodiments lighting shows and effects composed by the light system composer 5004 can be combined with other files from another computer system, such as one that includes an XML parser that parses an XML document output by the light system composer 5004 along with XML elements relevant to the other computer. In embodiments lighting shows are combined by adding additional elements to an XML file that contains a lighting show or effect. In embodiments the other computer system comprises a browser and the user of the browser can edit the XML file using the browser to edit the lighting show generated by the lighting show composer. In embodiments the light system engine 5008 includes a server, wherein the server is capable of receiving data over the Internet. In embodiments the light system engine 5008 is capable of handling multiple zones of light systems, wherein each zone of light systems has a distinct mapping. In embodiments the multiple zones are synchronized using the internal clock of the light system engine 5008. Multiple zones could for example, comprise

different treatment rooms, operating rooms, offices or the like of a hospital. For example, an alert could be directed to a particular portion of a hospital by directing it to display an emergency light show, indicating that an emergency is occurring. Through a feedback loop, the hospital's network could, for example, detect the presence of a doctor (such as through an RFID tag, cellphone, pager, or similar device) and alert that doctor to an emergency by changing the lighting conditions in proximity to the doctor, without requiring a loudspeaker or similar mechanism that might disturb patients throughout the hospital.

The methods and systems included herein include methods and systems for providing a mapping facility 5002 of the light system manager 5000 for mapping locations of a plurality of light systems. In embodiments, the mapping system discovers lighting systems in an environment, using techniques described above. In embodiments, the mapping facility then maps light systems in a two-dimensional space, such as using a graphical user interface.

In embodiments of the invention, the light system engine 5008 comprises a personal computer with a Linux operating system. In embodiments the light system engine is associated with a bridge to a DMX or DALI system.

The term "network" as used herein refers to any interconnection of two or more devices (including controllers or processors) that facilitates the transport of information (e.g. for device control, data storage, data exchange, etc.) between any two or more devices and/or among multiple devices coupled to the network. As should be readily appreciated, various implementations of networks suitable for interconnecting multiple devices may include any of a variety of network topologies and employ any of a variety of communication protocols. Additionally, in various networks according to the present invention, any one connection between two devices may represent a dedicated connection between the two systems, or alternatively a non-dedicated connection. In addition to carrying information intended for the two devices, such a non-dedicated connection may carry information not necessarily intended for either of the two devices

(e.g., an open network connection). Furthermore, it should be readily appreciated that various networks of devices as discussed herein may employ one or more wireless, wire/cable, and/or fiber optic links to facilitate information transport throughout the network.

Fig. 16 illustrates one of many possible examples of a networked lighting system 100 in which a number of lighting units 102 are coupled together to form the networked lighting system.

The networked lighting system may be configured flexibly to include one or more user interfaces, as well as one or more signal sources such as sensors/transducers. For example, one or more user interfaces and/or one or more signal sources such as sensors/transducers (as discussed above in connection with Fig. 1) may be associated with any one or more of the lighting units of the networked lighting system. Alternatively (or in addition to the foregoing), one or more user interfaces and/or one or more signal sources may be implemented as "stand alone" components in the networked lighting system 100. Whether stand alone components or particularly associated with one or more lighting units 102, these devices may be "shared" by the lighting units of the networked lighting system. Stated differently, one or more user interfaces and/or one or more signal sources such as sensors/transducers may constitute "shared resources" in the networked lighting system that may be used in connection with controlling any one or more of the lighting units of the system.

Another aspect of the present invention relates to maintaining a system of addressable systems. In an embodiment, a lighting unit 102 may include a power monitoring system, as indicated above, and this system may be used to monitor the performance of associated systems (e.g. lighting unit 102) and feedback information relating to the same. For example, a lighting unit 102 may control an illumination source and the illumination source may include three colors of LEDs (e.g. red, green and blue). A central controller may communicate a status command that directs each of the addressable lighting unit 102 to turn on a specific color and the power monitoring system

may monitor the power drawn by the lighting unit to indicate the condition of the illumination source. For example, the command may instruct a lighting unit to energize its red LEDs and following the energization, the lighting unit controller may monitor the power draw. If some of the red LEDs are not functioning or not functioning properly the power draw would be less then an expected value and a fault condition may be noted. A testing sequence could be generated and communicated by the central controller such that all of the lighting units are inspected using such a system. Following this routine, a system report may be generated indicating lighting units that may not be functioning properly. The report may indicate the lighting unit, associated lighting unit controller, position and any other relevant information. In embodiments, the system report may be delivered to a processor for identifying changes to the lighting configuration, such as changes to the addresses or data streams, or the handling of them, in lighting units 102. Thus, a "self-healing" lighting configuration can be created, that corrects defects that arise as a result of failure of one or more lighting units 102 or components thereof within the configuration.

A lighting unit 102 may also include a physical data interface 4904, such as a USB port, another data port, an Ethernet card, a serial port, a wire, a direct network connection, a multi-port servicing multiple protocols, a memory stick, a smart socket, a smart cable, a smart bulb, a file player or the like. These data interfaces 4904 may facilitate coupling multiple lighting units together as a networked lighting system, in which at least some of the lighting units are addressable (e.g., have particular identifiers or addresses) and are responsive to particular data transported across the network.

A lighting unit 102 may have a user interface 4908. The term "user interface" as used herein refers to an interface between a human user or operator and one or more devices that enables communication between the user and the device(s). Examples of user interfaces that may be employed in various implementations of the present invention include, but are not limited to, a dipswitch, slider, dial, button, keyboard, mouse, trackball, pointer, joystick, player, voice recognition interface, wireless interface, touch screen, switch, human-machine interface, operator interface, potentiometer, keypad,

various types of game controllers, display screens, various types of graphical user interfaces (GUIs), microphones and other types of sensors that may receive some form of human-generated stimulus and generate a signal in response thereto. User interfaces 4908 may be provided to facilitate any of a number of user-selectable settings or functions (e.g., generally controlling the light output of the lighting unit 102, changing and/or selecting various pre-programmed lighting effects to be generated by the lighting unit, changing and/or selecting various parameters of selected lighting effects, setting particular identifiers such as addresses or serial numbers for the lighting unit, etc.). In various embodiments, the communication between the user interface 4908 and the lighting unit may be accomplished through wire or cable, or wireless transmission.

In one implementation, the processor 3600 of the lighting unit 102 monitors the user interface 4908 and controls one or more of the light sources 300 based at least in part on a user's operation of the interface. For example, the processor 3600 may be configured to respond to operation of the user interface by originating one or more control signals for controlling one or more of the light sources. Alternatively, the processor 3600 may be configured to respond by selecting one or more pre-programmed control signals stored in memory, modifying control signals generated by executing a lighting program, selecting and executing a new lighting program from memory, or otherwise affecting the radiation generated by one or more of the light sources.

In particular, in one implementation, the user interface 4908 may constitute one or more switches (e.g., a standard wall switch) that interrupt power to the processor 3600. In one aspect of this implementation, the processor 3600 is configured to monitor the power as controlled by the user interface, and in turn control one or more of the light sources 300 based at least in part on a duration of a power interruption caused by operation of the user interface. As discussed above, the processor may be particularly configured to respond to a predetermined duration of a power interruption by, for example, selecting one or more pre-programmed control signals stored in memory, modifying control signals generated by executing a lighting program, selecting and

executing a new lighting program from memory, or otherwise affecting the radiation generated by one or more of the light sources.

In other embodiments of the present invention it may be desirable to limit user control. Medical and surgical environments, such as operating theatres, may require highly specified lighting conditions, in which case it may be desirable to ensure that lighting conditions are not changed over time. Unfortunately, over time, the maintenance of an environment, which includes light bulb replacement, often means that a lighting unit 102, such as a bulb, is selected whose properties differ from the original design. This may include differing wattages, color temperatures, spectral properties, or other characteristics. It is desirable to have facilities for improving the designer's control over future lighting of an environment. A lighting unit 102 may include a dial that allows a user to select one or more colors or color temperatures from a scale. For example, the scale could include different color temperatures of white light. The lighting designer for the environment can specify use of a particular color temperature of light, which the installer can select by setting the right position on the scale with the dial. A slide mechanism can be used much like the dial to set a particular color temperature of white light, or to select a particular color of non-white light, in either case on a scale. Again, the designer can specify a particular setting, and the installer can set it according to the design plan. Providing adjustable lighting units 102 offers designers and installers much greater control over the correct maintenance of the lighting of the environment.

In embodiments, the fixture, socket or lighting unit 102 can command color setting at installation, either a new setting or a fine adjustment to provide precise color control. In embodiments, the lighting unit 102 allows color temperature control as described elsewhere. The lighting unit 102 is settable, but the fixture itself stores an instruction or value for the setting of a particular color temperature or color. Since the fixture is set, the designer or architect can insure that all settable lighting units 102 will be set correctly when they are installed or replaced. An addressable fixture can be accomplished through a cable connection where the distal end of the cable, at the fixture, has a value programmed or set. The value is set through storage in a data storage facility,

such as memory, or over the power lines. A physical connection can be made with a small handheld device, such as a Zapi available from Color Kinetics, to create and set the set of parameters for that fixture and others. If the environment changes over time, as for example during a remodeling, then those values can be updated and changed to reflect a new look for the environment. A person could either go from fixture to fixture to reset those values or change those parameters remotely to set an entire installation quickly. Once the area is remodeled or repainted, as in the lobby of a hotel for example, the color temperature or color can be reset and, for example, have all lighting units 102 in the lobby set to white light of 3500K. Then, in the future, is any lighting unit 102 is replaced or upgraded, any bulb plugged in can be set to that new value. Changes to the installation parameters can be done in various ways, such as by network commands, or wireless communication, such as RF or IR communication.

In various embodiments, the setting can occur in the fixture or socket, in the distal end of a cable, in the proximal end of the cable, or in a central controller. The setting can be a piece of memory embedded in any of those elements with a facility for reading out the data upon startup of the lighting unit 102.

In other embodiments it may be desirable to prevent or deter user adjustment. A lighting unit 102 can be programmed to allow adjustment and changes to parameters by a supervisor, lighting designer or installer, but not by other users. Such systems can incorporate a lockout facility to prevent others from easily changing the settings. This can take the form of memory to store the current state but allow only a password-enabled user to make changes. One embodiment is a lighting unit 102 that is connected to a network or to a device that allows access to the lighting unit 102 or network. The device can be an authorized device whose initial communication establishes trust between two devices or between the device and network. This device can, once having established the connection, allow for the selection or modification of pattern, color, effect or relationship between other devices such as ambient sensors or external devices..

In other embodiments, the lighting designer can specify changes in color over time or based on time of day or season of year. It is beneficial for a lighting unit 102 to

measure the amount of time that it has been on and store information in a compact form as to its lighting history. This provides a useful history of the use of the light and can be correlated to use lifetime and power draw, among other measurements. An intelligent networked lighting unit 102 can store a wide variety of useful information about its own state over time and the environmental state of its surroundings. A lighting unit can store a histogram, a chart representing value and time of lighting over time. The histogram can be stored in memory. A histogram can chart on time versus off time for a lighting unit 102. A histogram can be correlated to other data, such as room habitation, to develop models of patterns of use, which can then be tied into a central controller, such as integrated with a building control system, such as a hospital system.

Although most lighting units 102 have a switch or control of some kind to turn on the light, and that is possible in medical and surgical applications to have a simple, low cost, mechanism for turning the device on and having it run constantly. If it is a wired system, then the simple connection, once disconnected, will turn off the lighting unit 102. Other user interfaces 4908 suitable for medical and surgical environments may include a toggle, membrane switch, a mechanical 'buckle' or 'toggle'that can be used to actuate an electrical switch and allow a completely sealed container. The back of the coin-sized devices shown above can incorporate such a device to toggle the power on for the light source. Another more modern variant are the small, actuated membrane switches, which sometimes also use a mechanical toggle to trigger a switch. It is also possible to have such a device provide on-off control as well. It may be desirable to control devices by rotating one section with respect to another to complete electrical circuit contact. It may be desirable to include an insulating strip that must be removed or pulled out to activate the device by completing a circuit. It may be desirable to include a. simple 'tilt' type sensor or MEMS device such as used in air-bag sensors can be used to trigger an on shaking or on an impact condition. This allows a simple rap or tap to activate the light source or perhaps to change it's lighting condition or type such as intensity or color. In embodiments a lighting unit 102 may be "on" at all times and the lighting unit 102 may be charged quickly and used at that time. In embodiments a small

reed-relay or Hall-effect sensor can be incorporated so when a magnetic material is brought within the proximity of the device it completes a power circuit. The magnet may serve double-duty by fastening the lighting unit as well.

The lighting unit 102 can include or be coupled with an addressing facility 6600 to assist with addressing data or control instructions to a particular lighting unit 102 among a plurality of lighting units. The addressing facility 6600 may include a dipswitch, a bar code, a factory-settable address, a set and forget address, a power detection addressing facility, a photographic feedback addressing facility, a serial addressing protocol, a table-lookup addressing facility, a sensor-feedback addressing facility, a manual addressing facility, or any other kind of facility for providing an address to a device, such as a lighting unit 102.

The term "addressable" is used herein to refer to a device (e.g., a light source in general, a lighting unit 102 or fixture, a controller or processor associated with one or more light sources or lighting units, other non-lighting related devices, etc.) that is configured to receive information (e.g., data) intended for multiple devices, including itself, and to selectively respond to particular information intended for it. The term "addressable" often is used in connection with a networked environment (or a "network," discussed further below), in which multiple devices are coupled together via some communications medium or media.

In one implementation, one or more devices coupled to a network may serve as a controller for one or more other devices coupled to the network (e.g., in a master / slave relationship). In another implementation, a networked environment may include one or more dedicated controllers that are configured to control one or more of the devices coupled to the network. Generally, multiple devices coupled to the network each may have access to data that is present on the communications medium or media; however, a given device may be "addressable" in that it is configured to selectively exchange data with (i.e., receive data from and/or transmit data to) the network, based, for example, on one or more particular identifiers (e.g., "addresses") assigned to it.

Many of the embodiments illustrated herein involve setting an address in a lighting unit 102. However, a method or system according to the principles of the present invention may involve selecting a mode, setting, program or other setting in the lighting unit 102. An embodiment may also involve the modification of a mode, setting, program or other setting in the lighting unit 102. In an embodiment, a programming device may be used to select a preprogrammed mode in the lighting unit 102. For example, a user may select a mode using a programming device and then communicate the selection to the lighting unit 102 wherein the lighting unit 102 would then select the corresponding mode. The programming device may be preset with modes corresponding to the modes in the lighting unit 102. For example, the lighting unit 102 may have four preprogrammed modes: color wash, static red, static green, static blue, and random color generation. The programming device may have the same four mode selections available such that the user can make the selection on the programming device and then communicate the selection to the lighting unit 102. Upon receipt of the selection, the lighting unit 102 may select the corresponding mode from memory for execution by the processor 3600. In an embodiment, the programming device may have a mode indicator stored in its memory such that the mode indicator indicates a particular mode or lighting program or the like. For example, the programming device may have a mode indicator stored in memory indicating the selection and communication of such a mode indicator would initiate or set a mode in the lighting system corresponding to the indicator. An embodiment of the present invention may involve using the programming device to read the available selections from the lighting systems memory and then present the available selections to the user. The user can then select the desired mode and communicate the selection back to the lighting unit 102. In an embodiment, the lighting system may receive the selection and initiate execution of the corresponding mode.

In an embodiment, the programming device may be used to download a lighting mode, program, setting or the like to a lighting unit 102. The lighting unit 102 may store the lighting mode in its memory. The lighting unit 102 may be arranged to execute the mode upon download and or the mode may be available for selection at a later time. For

example, the programming device may have one or more lighting programs stored in its memory. A user may select one or more of the lighting programs on the programming device and then cause the programming device to download the selected program(s) to a lighting unit 102. The lighting unit 102 may then store the lighting program(s) in its memory. The lighting unit 102 and or downloaded program(s) may be arranged such that the lighting system's processor 3600 executes one of the downloaded programs automatically.

More specifically, one embodiment of the present invention is directed to a system of multiple controllable lighting units coupled together in any of a variety of configurations to form a networked lighting system. In one aspect of this embodiment, each lighting unit has one or more unique identifiers (e.g., a serial number, a network address, etc.) that may be pre-programmed at the time of manufacture and/or installation of the lighting unit, wherein the identifiers facilitate the communication of information between respective lighting units and one or more lighting system controllers. In another aspect of this embodiment, each lighting unit may be flexibly deployed in a variety of physical configurations with respect to other lighting units of the system, depending on the needs of a given installation.

One issue that may arise in such a system of multiple controllable lighting units is that upon deployment of the lighting units for a given installation, it is in some cases challenging to configure one or more system controllers *a priori* with some type of mapping information that provides a relationship between the identifier for each lighting unit and its physical location relative to other lighting units in the system. In particular, a lighting system designer/installer may desire to purchase a number of individual lighting units each pre-programmed with a unique identifier (e.g., serial number), and then flexibly deploy and interconnect the lighting units in any of a variety of configurations to implement a networked lighting system. At some point before operation, however, the system needs to know the identifiers of the controllable lighting units deployed, and preferably their physical location relative to other units in the system, so that each unit may be appropriately controlled to realize system-wide lighting effects.

One way to accomplish this is to have one or more system operators and/or programmers manually create one or more custom system configuration files containing the individual identifiers for each lighting unit and corresponding mapping information that provides some means of identifying the relative physical locations of lighting units in the system. As the number of lighting units deployed in a given system increases and the physical geometry of the system becomes more complex, however, Applicants have recognized and appreciated that this process quickly can become unwieldy.

In view of the foregoing, one embodiment of the invention is directed to methods and apparatus that facilitate a determination of the respective identifiers of controllable lighting units coupled together to form a networked lighting system. In one aspect of this embodiment, each lighting unit of the system has a pre-programmed multiple-bit binary identifier, and a determination algorithm is implemented to iteratively determine (i.e., "learn") the identifiers of all lighting units that make up the system. In various aspects, such determination/learning algorithms may employ a variety of detection schemes during the identifier determination process, including, but not limited to, monitoring a power drawn by lighting units at particular points of the process, and/or monitoring an illumination state of one or more lighting units at particular points of the determination process.

Once the collection of identifiers for all lighting units of the system is determined (or manually entered), another embodiment of the present invention is directed to facilitating the compilation of mapping information that relates the identified lighting units to their relative physical locations in the installation. In various aspects of this embodiment, the mapping information compilation process may be facilitated by one or more graphics user interfaces that enable a system operator and/or programmer to conveniently configure the system based on either learned and/or manually entered identifiers of the lighting units, as well as one or more graphic representations of the physical layout of the lighting units relative to one another.

Once all lighting unit identifiers are known and mapping information for the system is compiled, yet another embodiment of the invention is directed to the control of such a lighting system using various command hierarchies in conjunction with various system configurations and communication protocols. For example, one embodiment of the invention is directed to methods and apparatus that facilitate the communication of "high level" lighting commands and/or other programming information throughout some portion of the networked lighting system via an Ethernet-based implementation, while the "lower level" actual control of individual lighting units is accomplished using a DMX-based implementation (which is conventionally used in some professional lighting applications). In one aspect of this embodiment, a number of lighting unit controllers are deployed throughout the networked lighting system to communicate with one or more central system controllers via an Ethernet-based protocol. Such lighting unit controllers subsequently process the Ethernet-based information to provide DMX-based control signals to one or more lighting units.

In an embodiment a power-monitoring system may monitor the power draw as particular lighting units 102 are turned on or off and allow a processor to calculate inferences about what lighting units have what locations based on the power draw. In another embodiment, the lighting unit controller may not include a power monitoring system but the methodology of identifying lighting unit addresses according to the principles of the present invention may still be achieved. For example, rather than monitoring the power consumed by one or more lighting units, a visible interpretation of the individual lighting units may be recorded, either by human intervention or another image capture system such as a camera or video recorder. In this case, the images of the light emitted by the individual lighting units may be recorded for each bit identification and it may not be necessary to go up and down the binary task tree as identified above.

Another aspect of the present invention relates to systems and methods of communicating to large-scale networks of lighting units. In an embodiment, the communication to the lighting units originates from a central controller where

information is communicated in high level commands to lighting unit controllers. The high level commands are then interpreted by the lighting unit controllers, and the lighting unit controllers generate lighting unit commands. In an embodiment, the lighting unit controller may include its own address such that commands can be directed to the associated lighting units through controller-addressed information. For example, the central controller may communicate light controller addressed information that contains instructions for a particular lighting effect. The lighting unit controller may monitor a network for its own address and once heard, read the associated information. The information may direct the lighting unit controller to generate a dynamic lighting effect (e.g. a moving rainbow of colors) and then communicate control signals to its associated lighting units to effectuate the lighting effect. In an embodiment, the lighting unit controller may also include group address information. For example, it may include a universe address that associates the controller with other controllers or systems to create a universe of controllers that can be addressed as a group; or it may include a broadcast address such that broadcast commands can be sent to all controllers on the network.

Embodiments may include a serial or linear addressing protocol where a given lighting unit 102 receives data, initiates a lighting condition based on the data, modifies a portion of the data to reflect that the portion is used, and passes the data on to the next lighting unit 102 in the series, which responds to an unmodified portion of the data.

An authoring facility 7400 may include a graphical user interface that allows a user to author shows, lighting control instructions, effects, meta effects, object-oriented effects, time-based effects, geometry-based effects, effects that correspond to external signals, entertainment effects, effects coupled to entertainment signals, effects that correspond to information, and the like. A graphical user interface of the mapping facility 5002 of the authoring computer 5010 can display a two-dimensional map, or it may represent a two-dimensional space in another way, such as with a coordinate system, such as Cartesian, polar or spherical coordinates. In embodiments, lights in an array, such as a rectangular array, can be represented as elements in a matrix, such as with the lower left corner being represented as the origin (0, 0) and each other light being

represented as a coordinate pair (x, y), with x being the number of positions away from the origin in the horizontal direction and y being the number of positions away from the origin in the vertical direction. Thus, the coordinate (3, 4) can indicate a light system three positions away from the origin in the horizontal direction and four positions away from the origin in the vertical direction. Using such a coordinate mapping, it is possible to map addresses of real world lighting systems into a virtual environment, where control signals can be generated and associated geometrically with the lighting systems. With conventional addressable lighting systems, a Cartesian coordinate system may allow for mapping of light system locations to authoring systems for light shows.

It may be convenient to map lighting systems in other ways. For example, a rectangular array can be formed by suitably arranging a curvilinear string of lighting units 102. The string of lighting units may use a serial addressing protocol, wherein each lighting unit in the string reads, for example, the last unaltered byte of data in a data stream and alters that byte so that the next lighting unit will read the next byte of data. If the number of lighting units N in a rectangular array of lighting units is known, along with the number of rows in which the lighting units are disposed, then, using a table or similar facility, a conversion can be made from a serial arrangement of lighting units 1 to N to another coordinate system, such as a Cartesian coordinate system. Thus, control signals can be mapped from one system to the other system. Similarly, effects and shows generated for particular configurations can be mapped to new configurations, such as any configurations that can be created by arranging a string of lighting units, whether the share is rectangular, square, circular, triangular, or has some other geometry. In embodiments, once a coordinate transformation is known for setting out a particular geometry of lights, such as building a two-dimensional geometry with a curvilinear string of lighting units, the transformation can be stored as a table or similar facility in connection with the light system manager 5000, so that shows authored using one authoring facility can be converted into shows suitable for that particular geometric arrangement of lighting units using the light system engine 5008. The light system composer 5004 can store pre-arranged effects that are suitable for known geometries, such as a color chasing rainbow moving across a tile light with sixteen lighting units in a

four-by-four array, a burst effect moving outward from the center of an eight-by-eight array of lighting units, or many others.

Various other geometrical configurations of lighting units are so widely used as to benefit from the storing of pre-authored coordinate transformations, shows and effects. For example, a rectangular configuration is widely employed in architectural lighting environments, such as to light the perimeter of a rectangular item, such as a space, a room, a hallway, a stage, a table, an elevator, an aisle, a ceiling, a wall, an exterior wall, a sign, a billboard, a machine, a vending machine, a gaming machine, a display, a video screen, a swimming pool, a spa, a walkway, a sidewalk, a track, a roadway, a door, a tile, an item of furniture, a box, a housing, a fence, a railing, a deck, or any other rectangular item.

A triangular configuration can be created, using a curvilinear string of lighting units, or by placing individual addressable lighting units in the configuration. Again, once the locations of lighting units and the dimensions of the triangle are known, a transformation can be made from one coordinate system to another, and pre-arranged effects and shows can be stored for triangular configurations of any selected number of lighting units. Triangular configurations can be used in many environments, such as for lighting triangular faces or items, such as architectural features, alcoves, tiles, ceilings, floors, doors, appliances, boxes, works of art, or any other triangular items.

Lighting units 102 can be configured in any arbitrary geometry, not limited to two-dimensional configurations. The three-dimensional coordinates (x, y, z) can be converted based on the positions of the individual lighting units in the string. Once a conversion is known between the (x, y, z) coordinates and the string positions of the lighting units, shows authored in Cartesian coordinates, such as for individually addressable lighting units, can be converted to shows for a string of lighting units, or vice versa. Pre-stored shows and effects can be authored for any geometry, whether it is a string or a two- or three-dimensional shape. These include rectangles, squares, triangles, geometric solids, spheres, pyramids, tetrahedrons, polyhedrons, cylinders, boxes and

many others, including shapes found in nature, such as those of trees, bushes, hills, or other features.

Referring to Fig. 17, the light system manager 5000 may operate in part on the authoring computer 5010, which may include a mapping facility 5002. The mapping facility 5002 may include a graphical user interface, or management tool, which may assist a user in mapping lighting units to locations. The management tool may include various panes, graphs or tables, each displayed in a window of the management tool. A lights/interfaces pane lists lighting units or lighting unit interfaces that are capable of being managed by the management tool. Interfaces may include power/data supplies (PDS) 1758 for one or more lighting systems, DMX interfaces, DALI interfaces, interfaces for individual lighting units, interfaces for a tile lighting unit, or other suitable interfaces.

The light system composer 5008 can be provided, running on the authoring computer 5010, for authoring lighting shows comprised of various lighting effects. The lighting shows can be downloaded to the light system engine 5008, to be executed on lighting units 102. The light system composer 5008 is preferably provided with a graphical user interface, with which a lighting show developer interacts to develop a lighting show for a plurality of lighting units 102 that are mapped to locations through the mapping facility 5002. The user interface supports the convenient generation of lighting effects, embodying object-oriented programming approaches.

Referring to Fig. 19, a medical environment is depicted in which a health care provider 1900 provides health care services to a patient 1902 under a lighting system 1908 that includes a plurality of lighting units 102. The lighting units 102 can produce white light, such as white light of a selected color temperature, as well as colored light. In embodiments, the lighting system 1908 can provide both white and non-white light under control of a processor 3600. The processor 3600 can be part of another lighting system, such as the lighting system for an operating theatre, emergency room, or other medical environment. The lighting system 1908 can be used to provide controlled light

to the area of the patient 1902. Control of the light can be by direct control or by remote control. The health care provider 1900 or other operator can control the light system 1908 to provide exactly the desired lighting conditions. For example, a surgeon may have strong preferences for a given color or color or color temperature of light, while another surgeon may have different preferences. The system 1908 allows each one to select a preferred color and color temperature. Also, during a procedure, such as a surgery, it may be desirable to change the lighting conditions. For example, an artery, being red, will appear more vivid under red light, while a vein would appear more vivid under blue light. Accordingly, depending on the particular system being viewed, the health care provider may change the light to fit the circumstances. Other medical applications may also benefit from changing lighting conditions under control; for example, a provider may wish to view an x-ray, chart, graph, picture, or other test result under ideal illumination conditions, or to view a patient under such conditions, such as to observe skin color or the like.

While all medical procedures and interventions can benefit from good lighting, there are a number of procedures whose efficacy would greatly benefit from the improved lighting methods and systems described herein. One result of better lighting alternatives may be a beneficial change in the procedure itself: smaller incisions, shorter procedures with less blood loss, and decreased complication rates resulting in decreased morbidity to the patients. Further, surgical techniques that are now too technically challenging to attempt outside specialized centers may become more broadly applicable.

In some embodiments the medical systems described herein can be single use and in others can be used, sterilized and reused multiple times. Additional features may include control of the light to adjust direction, level and type of output color to better illuminate surfaces.

The lighting systems described herein include small, easily handled lighting units 102 that can be quickly activated and then placed in or near the region of interest during

the medical procedure or surgery. Shapes and configurations can be widely varied to meet specific lighting needs.

Although for many medical applications, the light source 300 will be a color of white, the surgeon may wish to adjust or change the color to facilitate perception of the operative field. Many of the activation mechanisms shown above can be used as a simple interface (power cycle, tapping etc) to indicate a change in the light source. For example, if a switch is turned on and off in rapid succession through one of the many switch mechanisms described above, this could indicate to the light to change color temperature, or color. Non-visible wavelengths could also be used including IR and UV for particular applications for rendering elements visible using other viewing devices suitable for those wavelengths. UV fluorescing can indicate locations or medication or drug proximity and more. IR can be used to find or generate localized heating effects.

Microprocessor control and even direct voltage or current control can be used to provide variation in the light. Property changes can include hue, saturation and brightness to highlight particular areas. Red is often the color because of blood flow in the body and colors can be selected to highlight or diminish the visibility of different colors. This can enhance visibility of certain parts within the body or in any complex system.:

Many tools or supplies have been accidentally left in patients during surgery. These lost materials can cause complications later and the surgical process attempts to account for all materials to avoid this. There are a variety of way to track these materials and one or more of these can be incorporated into a lighting device such as described here. Such tracking facilities include strings – a simple string can allow you to determine quickly whether tools and instruments and other materials have been left inside the patient. Strings can be made from a wide variety of suitable materials including monofilament line, wire, suture line and natural materials. Tracking facilities include radiological tags. Radio-opaque tags or markers are well known and used to insure that sponges and other surgical equipment are not left inside the patient. The

housing 800 can be plastic and made or compounded with a radiopaque material such as barium sulfate to produce a radiopaque device. Other materials, known to those skilled in the art, can be added to increase the radiation opacity. Tracking facilities can include electronic article surveillance technology (EAS) such as that used in retail to track retail goods. Tracking facilities can include barcodes. In other embodiments a scanner in the OR can pass the light sources or for whatever application it is being used in and then subsequently a correspondence is made when devices are removed from the operation area in the patient. Tracking facilities can include RFID tags for radio frequency identification. RFID tags are tiny microchips, which listen for a radio query and respond by transmitting their unique ID code. Most RFID tags do not need batteries and instead use the power from the radio signal to transmit their response. Example suppliers include: Matrics, Alien Technology, and KSW-Microtec. The technology has been miniaturized to very small sizes (a flake of pepper for example) and can be integrated into a small light source.

The present invention provides a system for illuminating a body part, including a power source, an LED system connected to the power source, said LED system being adapted for illuminating the body organ, a medical instrument adapted for positioning the LED system in proximity to the body part to illuminate the body part, and a microprocessor for controlling the LED system. In one embodiment, the microprocessor is responsive to a signal relating to feature of the body part. The feature of the body part can be a structural condition. In one embodiment, the body part is illuminated in vivo. In one embodiment, the body part includes a lumen. In an embodiment, the medical instrument is adapted for insertion within a body cavity.

Fig. 20 depicts one embodiment of a system for illuminating a body part according to the present invention. This illustration shows a medical instrument for positioning the lighting unit 102 in proximity to a body part, here a conventional surgical retractor 2084 with the lighting unit 102 affixed to the anterior aspect of its retracting face 2090. The illustrated surgical retractor 2084 resembles a Richardson-type retractor, well-known in the art. Other medical instruments can be employed to bear the LED

system 2088 without departing from the scope of these systems and methods. Medical instruments bearing LED systems can be used for illuminating a body part.

In the embodiment depicted in Fig. 20, the retractor 2084 is shown elevating a segment of body tissue, here depicted as the edge of the liver. The illumination from the lighting unit 102 is directed at a body part, here the gallbladder 2110 and porta hepatis 2112. As used herein, the term body part refers to any part of the body. The term is meant to include without limitation any body part, whether that body part is described in anatomic, physiologic or topographic terms. A body part can be of any size, whether macroscopic or microscopic. The term body part can refer to a part of the body in vivo or ex vivo. The term ex vivo is understood to refer to any body part removed from body, whether that body part is living or is non-living. An ex vivo body part may comprise an organ for transplantation or for replantation. An ex vivo body part may comprise a pathological or a forensic specimen. An ex vivo body part can refer to a body part in vitro. The term body part shall be further understood to refer to the anatomic components of an organ. As an example, the appendix is understood to be an anatomic component of the organ known as the intestine.

In the illustrated embodiment, the porta hepatis 2112 is an anatomic region that is a body part. The porta hepatis 2112 is understood to bear a plurality of other body parts, including the portal vein, the hepatic artery, the hepatic nerve plexus, the hepatic ducts and the hepatic lymphatic vessels. The hepatic ducts from the liver and the cystic duct from the gallbladder converge to form the common bile duct; all these ducts are body parts as the term is used herein. Distinguishing these body parts from each other can be difficult in certain surgical situations. In the depicted embodiment, the lighting unit 102 is directed at the porta hepatis 2112 during a gallbladder procedure to facilitate identification of the relevant body parts. Directing lights of different colors at the discrete body parts can allow the operator more readily to decide which body part is which, a decision integral to a surgical operation.

In Fig. 20, the lighting unit 102 is shown arrayed at the distal edge of the retractor 2084 mounted on the undersurface of the retracting face 2090 of the retractor 2084. This arrangement interposes the retracting face 2090 of the retractor 2084 between the body tissue, here the edge of the liver 2104, and the LED system 2088 so that a retracting force on the body tissue, here the edge of the liver 2104, does not impinge upon the LED system 2088. The LED system 2088 in the illustrated embodiment is arranged linearly along the retracting face 2090 of the retractor. Here the power cord 2108 is shown integrated with the handle 2106 of the retractor 2084. The systems described herein can be adapted for a plurality of medical instruments without departing from the scope of the invention. For example, a malleable retractor or a Deaver retractor can bear the LED system. Other types of retractors for specialized surgical applications can similarly be adapted to bear the LED system in any arrangement with respect to the retracting face that fits the particular surgical need. As an example, an LED system can be mounted on a flexible probe for illuminating a particular tissue where the probe does not serve the function of retraction. In an embodiment, an LED system can be directed at lymph nodes in the axilla or in the inguinal region following percutaneous access and subcutaneous dissection, illuminating these lymph nodes with a light color selected to illuminate a feature of the lymph nodes preferentially, such as their replacement with the melanotic tissue of malignant melanoma; the illumination of the lymph nodes can be simultaneously evaluated through endoscopy or videoendoscopy using minimally invasive techniques, thereby reducing the need for full operative lymphadenectomy with its consequent sequelae. This example is offered as an illustration of an embodiment of an application of the technologies described herein, but other examples and illustrations can be devised by those of ordinary skill in these arts that fall within the scope of the invention.

A plurality of other applications of these illumination systems can be readily envisioned by those of ordinary skill in the relevant arts. While the embodiment depicted in Fig. 20 shows a handheld retractor 2084 being used in an open surgical procedure, the illumination systems described herein can also be applied to endoscopic surgery, thoracoscopy or laparoscopy. Discrimination among the various body parts in a region

such as the porta hepatis 2112 can be particularly difficult during a laparoscopic procedure. As an alternate embodiment, the relevant anatomic structures can be illuminated using an LED system affixed to the instrumentation for laparoscopy, thereby facilitating the identification of the structures to be resected and the structures to be preserved during the laparoscopic procedure.

Other endoscopic applications will be apparent to those skilled in the art. As illustrative embodiments, an LED system can be combined with endoscopic instrumentation for the evaluation of intraluminal anatomy in gastrointestinal organs, in cardiovascular organs, in tracheobronchial organs or in genitourinary organs. A lumen is understood to be a body part, within the meaning of the latter term. The term lumen is understood to refer to a space in the interior of a hollow tubular structure. The term body part further comprises the wall of a hollow tubular structure surrounding the lumen. Subcutaneous uses of the illumination system can be envisioned to allow identification of body parts during endoscopic musculocutaneous flap elevation. Such body parts identified can include nerves, blood vessels, muscles and other tissues. Other embodiments can be readily envisioned by skilled practitioners without departing from the scope of the systems disclosed herein.

Fig. 21 further depicts a positioning arm 2032, a control module 2012 and a cable 2034 through which can pass the electrical signal to the LED system 2028, and the data signal to the lighting unit 102. Optionally, a data signal can pass to the sensor module (not shown) from a signal source 8400, such as a sensor. The cable 2034 can carry these sensor signals. The control module 2012 in the illustrated embodiment can contain the processor 3600, the power facility 1800, the sensor module for the sensor system and a processor 3600 for relating the signals received by the sensor system to the processor 3600, so that signals received by the sensor module affect the output characteristics of the lighting unit 102. The control module can further include a position controller (not shown). In the illustrated embodiment the positioning system 2010 comprises the positioning arm 2032, the position controller and a cable 2034. This depiction of a positioning system is merely illustrative. As the term is used herein, a positioning system

is understood to include any system capable of positioning the lighting unit 102 in a spatial relationship with the material being illuminated whereby the lighting unit 102 illuminates the material. A positioning system, therefore, can include an apparatus of any kind capable of positioning the lighting unit 102. A positioning system can comprise a human operator who is capable of positioning the lighting unit 102 in a spatial relationship with the material being illuminated whereby the lighting unit 102 illuminates the material. A positioning system can further comprise the cable if the cable is adapted for positioning the lighting unit 102 in a spatial relationship with the material being illuminated.

A plurality of positioning systems can be envisioned by practitioners in these arts that will conform to the features of the particular material being illuminated. For example, a positioning system adapted for microsurgery can be mounted on an operating microscope and can be controlled by a control module suitable for receiving positioning input from the microsurgeons. As one option for a positioning system to be used in microsurgery or other surgical procedures, a foot pedal system can provide positioning input, either using a foot-operated button, pedal or slide. As an alternative option, a manual control can be adapted for placement in the sterile field by convering the manual control with a sterile plastic bag or sheet so the microsurgeon can manipulate the control manually without compromising sterile technique.

As an example of a positioning system, a standard surgical light fixture can be equipped with a lighting unit 102 as disclosed herein. The standard surgical light fixture is capable of positioning the lighting unit 102 in a spatial relationship with the material being illuminated whereby the lighting unit 102 illuminates the material. This positioning system can be adjusted manually in the standard fashion well-known to surgical practitioners. Alternatively, the positioning system can be controlled in response to signals input from a separate control module. The positioning system can change its position to illuminate materials designated by the operator, either in response to direct input into the control module or as a response to signals transmitted to a sensor apparatus. Other embodiments of positioning systems can be envisioned by those skilled

in these arts. The scope of the term "positioning system" is not to be limited by the embodiment illustrated in this figure. A plurality of other positioning systems can be envisioned consistent with the systems and methods described herein.

Fig. 21 illustrates an embodiment of a positioning system 2010 where the lighting unit 102 is located at the distal end of the positioning arm 2032. In this embodiment, the position controller can transmit signals to the positioning arm 2032 to adjust its spatial position. These signals can be carried through the positioning cable 2038. Alternatively, the signals can be transmitted by infrared, by radio frequency, or by any other method known in the art. Remote access to the control module 2012 can permit the illumination system 2020 to be controlled from a great distance, for example in undersea or aerospace applications. Remote access also permits control of the lighting unit in hostile or inhospitable environments. Remote access to the control module is understood to comprise remote control. Techniques for remote control are familiar to practitioners in these arts.

In the illustrated embodiment, the positioning arm 2032 has a plurality of articulations 2040 permitting its three-dimensional motion. In the illustrated embodiment, the articulations 2040 are arranged to provide the flexibility required by a particular technical application. Positioning can be accomplished with other mechanisms besides those depicted in Fig. 21. These mechanisms will be familiar to practitioners in the art. As depicted in Fig. 21, the proximal end of the positioning arm 2032 is anchored to a base 2026. The articulation connecting the positioning arm 2032 to the base 2026 can be arranged to permit motion along an axis parallel to or perpendicular to the axes of motion permitted by the other articulations 2040.

The positioning system depicted in Fig. 21 is merely one embodiment of the systems described herein. A plurality of other embodiments are available, as will be realized by practitioners of ordinary skill in the relevant arts. In one embodiment, the positioning system 2010 can be configured for large-scale applications, such as the evaluation of sheet metal or structural steel. Alternatively, the positioning system 2010

can be adapted for microscopic adjustments in position. It is understood that the light provided by the illumination system can be used for a plurality of precision applications. Fine three-dimensional control of the illumination pattern can direct the light to an exact three-dimensional position. In an alternate embodiment, signals from the sensor module can be used to control or to activate the position controller, so that the positioning system 2010 can be directed to move the lighting unit 102 in response to received sensor data. The illumination system comprising the lighting unit 102 allows the selection of a colored light predetermined to facilitate visualization of a target material. The strobing effect provided by an embodiment of the illumination system can permit freeze-frame imaging of dynamic processes, or can enhance the resolution of images acquired using conventional imaging modalities.

An embodiment of the illumination system can be used for taking photomicrographs. In another embodiment of the present invention, the system 100 may be used to improve the quality of robotic vision applications. In many robotic vision applications, such as location of semiconductor chips during the manufacturing process, reading of bar code matrices, location of robotic devices during manufacturing, or the like, a robotic camera is required to identify shapes or contrasts and to react accordingly. Different lighting conditions can have a dramatic effect on such vision systems. A method for improving the accuracy of such systems includes creating a color image via a sequence of multiple black and white images taken under multiple different strobed illuminating sequences. For example, the user may strobe a red strobe to get the red frame, a green strobe to get the green frame, and a blue strobe to get the blue frame. The strobing effect permits a higher resolution by the robotic camera of the image required for robotic vision. Other embodiments can be envisioned by those of ordinary skill in the art without departing from the scope of the present invention.

Fig. 22 shows a schematic diagram of the control module 2012. In the illustrated embodiment, the control module 2012 contains a power facility 1800, a first processor 3600, a sensor 2050 adapted for receiving signals from the sensors affixed to the distal end of the position arm, and a position controller 2052. The illustrated embodiment

features a second processor 2054 for relating data received by the sensor module 2050 to data for controlling the LED system. The position controller 2052 is adapted for adjusting the three-dimensional position of the positioning arm. The position controller 2052 can include an input device 2058 for receiving signals or data from an outside source. As an example, data can be input through a control panel operated by an operator. Data can be in the form of 3-D coordinates to which the position system is directed to move, or in any other form that can be envisioned by practitioners of these arts. Data can also be provided through computer programs that perform calculations in order to identify the 3-D coordinates to which the position system is directed to move. The input device 2058 can be configured to receive data received through a computer-based 3-dimensional simulator or virtual reality apparatus. Further examples of input devices 2058 can be envisioned by those of ordinary skill in the art without departing from the scope of this invention. The sensor module 2050 can be configured to receive any type of signal, as described in part above. A sensor module 2050 can comprise a light meter for measuring the intensity of the light reflected by the surface being illuminated. A sensor module 2050 can comprise a calorimeter, a spectrophotometer or a spectroscope, although other sensor modules and sensor systems can be employed without departing from the scope of the invention. A spectrophotometer is understood to be an instrument for measuring the intensity of light of a specific wavelength transmitted or reflected by a substance or a solution, giving a quantitative measure of the amount of material in the substance absorbing the light. Data received in the sensor module 2050 can be used to evaluate features of a material. In one embodiment, sensor module 2050 can be configured to provide data output to an output device 2060. The output data can include values that can be compared to a set of known values using algorithms familiar to those skilled in these arts. The relationship between the output data and the set of known values can be determined so as to yield meaningful information about the material being illuminated by the illumination system.

Fig. 23 depicts an embodiment of a lighting system capable of being directed by a part of an operator's body. The embodiment shown in Fig. 23 depicts a hand-held lighting system 2056 held in the operator's hand 2062. In the illustrated embodiment, the

lighting unit 102 is positioned at the distal end of a handheld wand 2068 that can be disposed in the operator's hand 2062 and directed towards a material 2070. The cable 2072 connects the lighting unit 102 to a power source (not shown). The cable 2072 transmits power signals and data signals to the lighting unit 102. In an alternate embodiment, sensors can be positioned at the distal end of the handheld wand 2068 to provide sensing data as described above. The signals from the sensors can be transmitted through the cable 2072 in one embodiment. In yet another embodiment, the handheld wand 2068 can include an imaging system for video imaging. This imaging system can permit display of real-time images, for example on a video screen. Alternatively, this imaging system can permit capture of still or motion images through appropriate software and hardware configurations. Illuminating the material 2070 with a variety of colors can result in significantly different images, as described in part above. Strobing the light can allow capture of still images and can allow improved improved resolution. The handheld system can be used for any application where using an operator's hand 2062 is advantageous in positioning the illumination system. In an embodiment, the system can be entirely handheld, as illustrated in Fig. 23. In an alternate embodiment, a wand bearing the LED can be affixed to a framework that supports it, whereby the positioning of the wand is facilitated by direct manipulation by the operator's hand. In yet another embodiment, the illumination system can be borne on the operator's hand by a band or a glove, so that the position of the illumination system can be directed by the movements of the operator's hand. In other embodiments, the illumination system can be affixed to or retained by other body parts, to be directed thereby.

In another embodiment of the present invention, the LEDs are displayed in proximity to the workpiece that requires illumination. Thus, an improved flashlight, light ring, wrist band or glove may include an array of LEDs that permit the user to vary the lighting conditions on the workpiece until the ideal conditions are recognized. This embodiment of the invention may be of particular value in applications in which the user is required to work with the user's hands in close proximity to a surface, such as in surgery, mechanical assembly or repair, particularly where the user cannot fit a large light source or where the workpiece is sensitive to heat that is produced by conventional

lights.

In one practice of a method for illuminating a material, a lighting unit 102, as described above, can be used. According to this practice, a lighting unit 102and a processor 3600 are provided. The practice of this method can then involve positioning the lighting unit 102 in a spatial relationship with the material to be illuminated. The positioning can take place manually or mechanically. The mechanical placement can be driven by input from an operator. Alternately, mechanical placement can be driven by a data set or a set of algorithms provided electronically. A first microprocessor can be provided for controlling the lighting unit 102. In an embodiment, a second microprocessor can be provided for positioning the positioning system in relation to the material to be illuminated. In yet another embodiment, a third microprocessor can be provided for processing data input from a sensor system or input from a control panel. Each microprocessor can be related to each other microprocessor, so that changes in one function can be related to changes in other functions.

In one practice, the method can further comprise providing an image capture system for recording an image of the material. An image capture system, as the term is used herein, comprises techniques using film-based methods, techniques using digital methods and techniques using any other methods for image capture. An image capture system further comprises methods that record an image as a set of electronic signals. Such an image can exist, for example, in a computer system. In the current arts, images can be captured on film, on magnetic tape as video or in digital format. Images that are captured using analog technologies can be converted to digital signals and captured in digital format. Images, once captured, can be further manipulated using photomanipulative software, for example Adobe Photoshop.TM.. Photomanipulative software is well-known in the art to permit modification of an image to enhance desirable visual features. An image once captured can be published using a variety of media, including paper, CD-ROM, floppy disc, other disc storage systems, or published on the Internet. The term recording as used herein refers to any image capture, whether permanent or temporary. An image capture system further includes those technologies

that record moving images, whether using film-based methods, videotape, digital methods or any other methods for capturing a moving image. An image capture system further includes those technologies that permit capture of a still image from moving images. An image, as the term is used herein, can include more than one image. As one embodiment, a photography system can be provided whereby the material being illuminated is photographed using film-based methods. In this embodiment, the LED system can be strobed to permit stop-action photography of a moving material.

In an alternative embodiment, a sensor system can be arranged to identify the characteristics of light reflected by a material and the lighting unit 102 can be controlled to reproduce a set of desired light characteristics so that the material will be optimally illuminated to achieve a desired photographic effect. This effect may be an aesthetic one, although industrial and medical effects can be achieved. For example, a set of characteristics for ambient light in the operating room can be identified by surgical personnel and replicated during surgery. Certain types of lighting conditions can be more suitable for certain operations. As another example, photography can be carried out using the lighting unit 102 to provide certain characteristics for the photographic illumination. As is well-known in the art, certain light tones and hues highlight certain colors for photography. Different light systems used for photography can cause different tones and hues to be recorded by the photograph. For example, incandescent light is known to produce more reddish skin tones, while fluorescent light is known to produce a bluish skin tone. The lighting unit 102 can be used to provide consistent tones and hues in a photographic subject from one lighting environment to another. Other desired photographic effects can be envisioned by those skilled in the relevant arts.

As one practice of a method for illuminating a material, a predetermined range of colors can be selected within the spectrum. The lighting unit 102 can then be controlled to generate these colors and to illuminate the material thereby. The material to be illuminated can be an inanimate entity. In one embodiment, a chemical reaction or its component reagents can be illuminated according to this method, whereby the illumination is understood to influence the characteristics of the chemical reaction. In

another embodiment, the method of illumination can be directed to a biological entity. The term biological entity as used herein includes any entity related to biology. The term biology refers to the science concerned with the phenomena of life and living organism. Hence, a biological entity can comprise a cell, a tissue, an organ, a body part, a cellular element, a living organism, a biological product, a chemical or an organic material produced by a biological entity or through biotechnology, or any other entity related to biology. Further, though, the term biological entity can refer to a substance that was once part of a living organism, including a substance extracted from a living organism and including a substance that is no longer alive. Pathological specimens are encompassed by the term biological entity. A living organism is called out as a particular embodiment of a biological entity, but this usage is not intended to narrow the scope of the term biological entity as it is used herein. In one practice of a method for illuminating a biological entity, that biological entity can be a living organism. A living organism can include cells, microorganisms, plants, animals or any other living organism.

As a practice of a method for illuminating a material, a predetermined desired illumination condition can be selected, and a material can be illuminated with a range of colors until the desired condition is attained. A range of colors can be selected according to this method, whereby the selected colors are capable of producing the desired condition. Optionally, an additional step of this practice comprises illuminating the material with the selected colors, so as to bring about the desired effect. This method can be applied to non-living or biological entities.

As a practice of a method for illumination, a material can be evaluated by selecting an area of the material to be evaluated, illuminating that area with a lighting unit 102, determining the characteristics of the light reflected from that area and comparing those characteristics of color and/or intensity with a set of known light parameters that relate to a feature of the material being evaluated. The feature being evaluated can be a normal feature or an abnormal feature of the material. As an example, the integrity of a tooth can be evaluated by directing light of a particular color at the tooth to identify those areas that are carious. Structural conditions of materials can be

evaluated by illuminating those materials and looking for abnormalities in reflected light. A practice of this method can be applied to biological entities. In forensic pathology, for example, various kinds of fillings for teeth can be distinguished by the way in which they reflect light of particular spectra. This allows identifications to be made based on dental records for forensic purposes. An embodiment of this method related to biological entities is adapted for use in a variety of medical applications, as will be described in more detail hereinafter.

In another embodiment of the present invention, as described in part above, a multicolor illuminator is provided for surgical illumination. Different body organs are typically low in relative color contrast. By changing color conditions in a controlled manner, the surgeon or assistant can increase this relative contrast to maximize the visibility of important surgical features, including internal organs and surgical instruments. Thus, if the surgeon is trying to avoid nerve tissue in a surgery, a light that is designed to create the maximum apparent contrast between nerve tissue color and other tissue will permit the greatest precision. Surgical lights of the present invention can be of any conventional configuration, such as large theater lights, or can be attached to surgical instruments, such as an endoscope, surgical gloves, clothing, or a scalpel.

A plurality of arrangements of LEDs can be envisioned by those of ordinary skill in these arts without departing from the scope of the invention. The lighting unit 102 is capable of being placed in proximity to the target organ by a surgical instrument. The term proximity as used herein refers to the degree of propinquity such that the illumination directed at the target body part is effective in accomplishing the clinical purpose intended by the operator. Thus, the proximity to the target body part is determined by the medical judgment of the operator. Since the lighting unit 102 does not produce heat, it can be positioned extremely close to the target body parts and other body parts without damaging the tissues. In an embodiment, the illumination assembly is capable of being directed at microsurgical structures without causing heat damage. The intensity of the light available from a lighting unit 102 is a feature that influences how

close the lighting unit 102needs to be positioned in order to accomplish the operator's clinical purpose.

As an alternative embodiment, the lighting unit 102 can be combined with other features on a medical instrument. The term medical instrument as used herein comprises surgical instruments. For example, the lighting unit 102 can be combined with a cautery apparatus or a smoke aspirator to be used in surgery. Fig. 24 depicts one embodiment of a surgical instrument that combines several other pieces of apparatus with the lighting unit 102. In Fig. 24, a Bovie cautery assembly 2132 is depicted, well-known in the surgical art. The cautery assembly 2132 includes a cautery tip 2134 and a handheld wand 2138. Imbedded in the wand 2138 in standard fashion is an array of control buttons 2140, an arrangement familiar to those in the art. At the distal tip of the handheld wand 2138 is a lighting unit 102. The power and data signals to the lighting unit 102 are carried through a cable 2148 affixed to the superior aspect of the handheld wand 2138. The cable 2148 joins with the Bovie power cord 2152 at the proximal end of the instrument to form a single united device cable 2150. In an alternate embodiment, the cable can be contained within the Bovie wand housing in proximity to the Bovie power cord.

The depicted embodiment permits the surgeon to direct LED light at a particular structure to identify it anatomically as part of cautery dissection. The spectral capacity of the lighting unit 102 is useful in identifying blood vessels, for example. Blood vessels embedded in tissues can be especially difficult to identify. The surgeon can dissect with the cautery tip 2134 of the illustrated embodiment while directing a light from the LED that is selected to highlight vascular structures. The tissues themselves would be distinguishable from the vascular structures based on the response of each set of structures to the light illumination from the lighting unit 102. The contrast between tissues requiring dissection and blood vessels to be preserved would be highlighted by the light illumination from the lighting unit 102. The surgeon, therefore, would be able to identify what structures are safe to transgress with cautery dissection. In this way, the surgeon could preserve blood vessels more readily, as required by the surgical procedure. Alternatively, the surgeon could identify blood vessels imbedded in tissues and take precautions to coagulate or ligate them effectively before transgressing them. The

illustrated embodiment represents only one possible arrangement of combined surgical instrumentation that employs an LED system. Other arrangements can be envisioned by those of ordinary skill in these arts. For specialized surgical applications, specialized combinations can be required. For example, particular instruments are employed in neurosurgery and in microsurgery. The same principles illustrated in the depicted embodiment of Fig. 24 can be applied in the fabrication of surgical instruments appropriate for these purposes.

As an alternate embodiment, the lighting unit 102 can be combined with a sensor system that provides signals that correlate with some characteristic of the body part being illuminated. As an example, Fig. 25 shows a lighting unit 100 affixed to a nasal endoscope 2092 being inserted transnasally 2094 to evaluate an intranasal or a pituitary tumor 2098. The endoscope 2092 is shown in this figure entering through the naris 2096 and being passed through the nasal airway 2086. The tumor 2098 is here shown at the superior aspect of the nasal airway 2086. The LED assembly 2100 can comprise an LED system (not shown) and a sensor system (not shown). The LED system can illuminate the intranasal and intrasellar structures with a range of colors, while the sensor system can provide data relating to the characteristics of the reflected light. The tumor 2098 can be identified by how it reflects the range of light being used to illuminate it. The sensor system can provide information about the characteristics of the reflected light, permitting the operator to identify the tumor 2098 in these remote locations. Further, such an endoscope 2092 can be combined with means familiar to practitioners in these arts for resecting or ablating a lesion.

The illumination system described herein is available for both direct illumination and transillumination. Transillumination is understood to refer to the method for examining a tissue, an anatomical structure or a body organ by the passage of light through it. For example, transilluminating a structure can help determine whether it is a cystic or a solid structure. One embodiment of an illumination system can employ LEDs to direct light of differing colors through a structure, whereby the appearance of the structure when subjected to such transillumination can contribute to its identification or

diagnosis. Transillumination using LED light can be directed to a plurality of structures. In addition to soft tissues and organs, teeth can be transilluminated to evaluate their integrity. An additional embodiment can employ a LED as an indwelling catheter in a luminal structure such as a duct. Illuminating the structure's interior can assist the surgeon in confirming its position during surgery. For example, in certain surgical circumstances, the position of the ureter is difficult to determine. Transilluminating the ureter using an LED system placed within its lumen can help the surgeon find the ureter during the dissection and avoid traumatizing it. Such an LED system could be placed cystoscopically, for example, as a catheter in a retrograde manner before commencing the open part of the operative procedure. In this embodiment, the LED system is particularly useful: not only can the color of the LED be varied in order to maximize the visibility of the transilluminated structure, but also the LED avoids the tissue-heating problem that accompanies traditional light sources.

Evaluation of a tissue illuminated by an embodiment of the illuminating system described herein can take place through direct inspection. In an alternative embodiment, evaluation can take place through examining the tissues using video cameras. In an illustrative embodiment, the tissues would be visualized on a screen. Color adjustments on the video monitor screen can enhance the particular effect being evaluated by the operating team. As an alternative embodiment, the illuminating system can be combined with a sensor module, as partially described above, whereby the intensity of the reflected light can be measured. As examples, a sensor module could provide for spectroscopic, colorometric or spectrophotometric analysis of the light signals reflected from the illuminated area. Other types of sensor modules can be devised by those skilled in the relevant arts. A sensor module can be combined with direct inspection for evaluating tissues. Alternatively, a sensor module can provide a means for remote evaluation of tissues in areas not available for direct inspection as a substitute for or as an adjunct to video visualization. Examples of such areas are well-known in the surgical arts. Examples of such areas can include transnasal endoscopic access to the pituitary, endoscopic evaluation of the cerebral ventricles, and intraspinal endoscopy, although other areas can be identified by those familiar with the particular anatomic regions and

relevant methods of surgical access. In addition to the abovementioned embodiments for use in living tissues, embodiments can be devised to permit evaluation of forensic tissues or pathology specimens using the illuminating systems disclosed herein.

Fig. 26 depicts an embodiment of the illumination system wherein the lighting unit 102 is mounted within a traditional surgical headlamp 2158 apparatus. In the illustrated embodiment, the lighting unit 102 is affixed to the headband 2160 using methods of attachment well-known to practitioners. Advantageously, however, the lighting unit 102 of the illustrated embodiment can be considerably lighter in weight than traditional headlamps. This reduces strain for the wearer and makes the headlamp apparatus more comfortable during long procedures. As depicted herein, the lighting unit 102 is connected to a power cord 2156. In distinction to traditional headlamp apparatus, however, the power cord 2156 for the lighting unit 102 is lightweight and non-bulky. The power cord 2156 can therefore be deployed around the headband 2160 itself, without having to be carried above the surgeon's head in a configuration that predisposes to torquing the headband and that collides with pieces of overhead equipment in the operating room. Furthermore, the power cord employed by the LED system avoids the problems inherent in the fiberoptic systems currently known in the surgical arts. In the traditional surgical headlamp as employed by practitioners in these arts, light is delivered to the lamp through a plurality of fiberoptic filaments bundled in a cable. With the systems known presently in the art, individual fiberoptic filaments are readily fractured during normal use, with a concomitant decrease in the intensity of the light generated by the headlamp. By contrast, the power cord 2156 for the lighting unit 102 does not contain fiberoptic elements but rather contains a wire carrying power to the lighting unit 102. This provides a more durable illumination unit than those known in the present art. Furthermore, the lighting unit 102 is sufficiently lightweight that it is capable of being integrated with the surgeon's magnifying loupes 2164.

Although the lighting unit 102 in the illustrated embodiment is affixed to a headband 2160, an alternative embodiment can permit eliminating the headband 2160 entirely and integrating the lighting unit 102 in the surgeon's spectacles or magnifying

loupes 2164. Fig. 27 depicts an embodiment of this latter arrangement. In this embodiment, an lighting unit 102 is shown integrated with the frame 2168 of the loupes 2164. The lighting unit 102 can be situated superiorly on the frame 2168 as depicted in this figure, or it can be arranged in any spatial relation to the frame 2168 that is advantageous for illuminating aspects of the surgical field. In this embodiment, the power cord 2162 can be positioned to follow the temple-piece 2170 of the loupes 2164.

The methods of the present invention comprise methods for diagnosing a condition of a body part. The methods for diagnosing a condition of a body part comprise selecting an area of the body part for evaluation, illuminating the area with an LED system, determining characteristics of the light reflected from the body part, and comparing the characteristics with known characteristics, wherein the known characteirstics relate to the condition of the body part. These methods can be applied to normal, nonpathological conditions of a body part. Alternatively, these methods can be used to identify pathological conditions of the body part.

It is understood that different body parts reflect light differently, depending upon their anatomic or physiological condition. For example, when subjected to room light, an ischemic body part can be perceived to be a purplish color, a color termed "dusky" or "cyanotic" by practitioners in these arts. Ischemia can therefore be at times diagnosed by direct inspection under room light. However, a multitude of situations exist where the vascular status of a body part cannot be evaluated by inspection under room light. For example, ischemia can be hard to see in muscles or in red organs. Further, skin ischemia is difficult to evaluate in room light in people with dark skins. The methods of the present invention include practices that permit the diagnosis of ischemia to be made by illuminating a body part with an LED system and comparing the reflected light with known light characteristics indicative of ischemia. These methods further can permit this diagnosis to be made at an earlier stage, when room light may not reveal color changes but when LED system illumination can permit the perception of more subtle color changes. A spectrometer or another sort of sensor system can be optionally employed to evaluate the color and/or the intensity of the light reflected from the illuminated body

part. For example, the systems and methods of the present invention can be adapted for the diagnosis of early circulatory compromise following vascular procedures. Common vascular procedures which can be complicated by circulatory compromise include surgical vascular reconstructions or revascularizations, surgical replantations, free tissue transfers, embolectomies, percutaneous angioplasties and related endovascular procedures, and medical thrombolytic therapies. The systems and methods disclosed herein can be adapted for the evaluation of tissues within the body by providing an LED system capable of implantation and removal and by providing a sensor system capable of implantation and removal, the former system adapted for directing illumination at a body part within the body and the latter system adapted for receiving color data from the light that is reflected or absorbed by the target body part. Systems and methods adapted for the evaluation of internal body parts can be advantageous in the monitoring of buried free flaps, for example. The lack of heat generated by the LED system makes it feasible to implant it without subjecting the surrounding tissues to heat trauma. Practitioners skilled in the relevant arts can identify other conditions besides ischemia that can be diagnosed using the methods disclosed herein. The full spectrum of light available from the LED systems disclosed herein is particularly advantageous for diagnosis of a plurality of conditions.

As a further example of the methods described herein, the LED system can be used to illuminate the retina for ophthalmological examination. Variation in light color can facilitate ophthalmological examination, for example the diagnosis of retinal hemorrhage or the evaluation of the retinal vessels. Practitioners of these arts will be able to envision other forms of retinopathy that are suitable for diagnosis using these methods. In one embodiment, an LED system can be integrated in a slit lamp apparatus for ophthalmological examination. In an additional embodiment, the LED system can be adapted for use in ophthalmological surgery. As an example, the LED system is capable of assisting in the localization of mature and hypermature cataracts, and is capable of assisting in the surgical extraction of cataracts.

One practice of these methods for diagnosing a condition of a body part can comprise administering an agent to the patient that will be delivered to the body part, whereby the agent alters the characteristic of the light reflected from the body part. An agent is any bioactive substance available for administration into the patient's tissues. An agent can include a drug, a radioisotope, a vitamin, a vital dye, a microorganism, a cell, a protein, a chemical, or any other substance understood to be bioactive. An agent can be administered by any route which will permit the agent to be delivered to the body part being evaluated. Administration can include intravenous injection, intramuscular injection, intraarterial injection, ingestion, inhalation, topical application, intrathecal delivery, intraluminal or intravesical delivery, subcutaneous delivery or any other route. The full spectrum of light provided by the systems and methods disclosed herein is advantageously employed in conjunction with certain administered agents.

An example of an agent known to alter the characteristic of light reflected from a body part is fluoroscein, a vital dye applied topically for ophthalmic purposes or injected intravenously to evaluate vascular perfusion. When illuminated by a Wood's lamp, fluoroscein glows green. Wood's lamp, though, is not adaptable to many surgical situations because of its physical configuration. Fluoroscein administered to remote body parts cannot be illuminated by a Wood's lamp, nor can the fluorescence be seen in a body part too remote to inspect. Illuminating the tissues with an LED system after the administration of a vital dye such as fluoroscein can produce a characteristic pattern of reflected light. This reflected light can be evaluated by direct visualization, by remote visualization or by a light sensor system. Other agents will be familiar to those of skill in these arts, whereby their administration permits the evaluation of a body part subjected to LED illumination.

As one example, gliomas are understood to have a different uptake of vital dye than other brain tissues. Directing an LED system at a glioma after the administration of vital dye can permit more complete excision of the tumor with preservation of surrounding normal brain tissue. This excision can be performed under the operating microscope, to which can be affixed the LED system for illuminating the brain tissues.

The lack of heat generation by the LED system makes it particularly advantageous in this setting. As an additional example, the LED system can be combined with fluoroscein dye applied topically to the surface of the eye for ophthalmological evaluation. As yet another example, the LED system combined with fluoroscein can permit diagnosis of ischemia in patients whose skin pigmentation may prevent the evaluation of skin ischemia using traditional methods such as Wood's lamp illumination. As disclosed in part above, these systems and methods can advantageously be directed towards body parts within the human body for evaluation of those body parts after the administration of an agent taken up by the body part.

The methods according to the present invention can be directed towards effecting a change in a material. In a practice of these methods, a change in a material can be effected by providing an LED system, selecting a range of colors from the spectrum that are known to produce the change in the material being illuminated, and illuminating the material with the LED system for a period of time predetermined to be effective in producing that change. The methods disclosed herein are directed to a plurality of materials, both non-biological materials and biological entities. A biological entity can include a living organism. A living organism can include a vertebrate. A living organism can include an invertebrate. A biological entity can be treated with light exposure in order to effect a change in its structure, physiology or psychology. For example, persons afflicted with the depressive syndrome termed seasonal affective disorder are understood to be benefited psychologically by exposure to illumination with light of known characteristics for predetermined periods of time. The illumination can be provided directly to the living organism, for example to the person with seasonal affective disorder. Alternatively, the illumination can be provided to the environment surrounding the person. For example, illumination can be provided by a room light comprising an LED system that can provide light with the predetermined characteristics.

As a practice of these methods, a condition of a patient can be treated. This practice can comprise providing an LED system, selecting a set of colors that produce a therapeutic effect and illuminating an area of the patient with the set of colors. A

therapeutic effect is understood to be any effect that improves health or well-being. According to this practice, a pathological condition can be treated. Alternatively, a normal condition can be treated to effect an enhanced state of well-being. The area being illuminated can include the external surface of the patient, to wit, the skin or any part of the skin. The external surface of the patient can be illuminated directly or via ambient illumination in the environment. These methods can be likewise applied to internal body parts of a patient.

Fig. 20 shows a practice of these methods. This figure depicts a patient 2180 afflicted with a lesion 2172 on an external surface, here shown to be his cheek. A lighting unit 102 is directed to provide direct illumination to the lesion 2172. Here the lighting unit 102 is shown affixed to the distal end of a positioning system 2182. Other arrangements for positioning the lighting unit 102 can be envisioned by those of ordinary skill in these arts. It is understood that illumination of dermatological lesions with different spectra of light can have therapeutic effect. For example, acne, Bowen's disease of the penis and certain other skin cancers have responded to treatment with illumination. As another example, certain intranasal conditions are understood to respond to illumination therapies. In one practice of these methods, an agent can be administered to the patient that alters or increases the therapeutic effect of the set of colors of light directed towards the area being treated.

A variety of agents are familiar to practitioners in the arts relating to phototherapy and photodynamic therapy. Photodynamic therapy (PDT) is understood to comprise certain procedures that include the steps of administering an agent to a patient and illuminating the patient with a light source. Laser light is typically involved in PDT. Since the illumination provided by the lighting unit 102 can provide full spectrum lighting, including infrared, visible and ultraviolet light spectra, the lighting unit 102 is available for those therapeutic applications that rely on non-visible light wavelengths. A number of applications of topical illumination have been described in the relevant arts. LED technology has the additional advantage of avoiding heat generation, so prolonged illumination can be accomplished without tissue damage.

Although the practice depicted in Fig. 28 shows a lighting unit 102 directed towards the skin of a patient 2180, various practices of this method can apply an LED system for illuminating body parts. Treatment can be directed towards internal or external body parts using modalities familiar to practitioners for accessing the particular body part. As described above, open surgical techniques or endoscopic techniques can be employed to access internal body parts. For example, an intraluminal tumor can be treated using these methods as applied through an endoscope such as a colonoscope or a cystoscope. Alternatively, illumination therapy can be provided following or during a surgical procedure. For example, following surgical extirpation of a tumor, an agent can be administered that is taken up by the residual microscopic tumor in the field and the surgical field can be illuminated by an LED system to sterilize any remaining tumor nodules. These methods can be employed palliatively for reducing tumor burden after gross excision. As another practice, these methods can be directed towards metastatic lesions that can be accessed directly or endoscopically.

Similarly, a surgeon in an operating theater could establish ideal lighting conditions for a particular type of surgery and reestablish or maintain those lighting conditions in a controlled manner. Moreover, due to the flexible digital control of the arrayed LEDs of the present invention, any number of desired lighting conditions may be programmed for maintenance or reestablishment.

Thus, the surgeon may select different lighting conditions depending on the surgical conditions. For example, different objects appear more or less vividly under different colors of light. If the surgeon is seeking high contrast, then lighting conditions can be preprogrammed to create the greatest contrast among the different elements that must be seen in the surgery.

While the invention has been described in connection with certain preferred embodiments, other embodiments may be recognized by one of ordinary skill in the art and are encompassed herein except as limited by the claims.